BACHELOR THESIS – ME 141502

DESIGNING PASSIVE HARMONIC FILTER AS A RESULT OF THE USE OF ELECTRIC PROPULSION SYSTEM WITH THREE-PHASE INDUCTION MOTOR ON OIL TANKER 1170GT

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DOUBLE DEGREE PROGRAM OF
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ABSTRACT

Harmonic is a frequency defect that have some negative effect to the electrical network system. In a ship, electrical network system are interconnected to each other to another electrical consumer device. The effect will impact all the device that connected to the electrical network system. This can be reducing the consumer devices reliability.

This research analyzed and simulate the effect of harmonic when there is no harmonic filter condition and with a passive harmonic filter for each operating condition on this ship. This research also includes the comparison diagram between no filter and with a passive harmonic filter condition, and a simulation report from the software.

The research results were VTHD value are comply with the classification standards and rules. Passive harmonic filter can reduce the VTHD value by reducing a specific harmonic order and the impact from reducing specific harmonic order can reduce the other harmonic order. Besides that, passive harmonic filter also can gain higher power factor (PF) value.

Keyword: total harmonic distortion, harmonic load flow analysis, passive filter, variable frequency drive

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ABSTRAK

Harmonisa adalah cacat gelombang yang memiliki beberapa efek negatif terhadap sistem jaringan listrik. Di dalam kapal, sistem jaringan listrik saling terhubung satu sama lain ke semua perangkat yang mengkonsumsi energi listrik dalam jaringan tersebut. Efeknya akan berdampak pada semua perangkat yang terhubung ke sistem jaringan listrik. Hal ini bisa mengurangi keandalan perangkat yang menggunakan energi listrik.

Penelitian ini menganalisis dan mensimulasikan efek harmonisa pada kondisi tanpa menggunakan filter harmonisa dan dengan filter harmonisa pasif untuk setiap kondisi pengoperasian pada kapal ini. Penelitian ini juga mencakup diagram perbandingan antara tidak ada filter dan dengan kondisi filter harmonisa pasif, serta laporan simulasi dari perangkat lunak.

Hasil penelitiannya adalah nilai VTHD sesuai dengan standar dan peraturan klasifikasi. Filter harmonisa pasif dapat mengurangi nilai VTHD dengan mengurangi orde harmonisa yang spesifik dan dampak dari pengurangan orde harmonisa tertentu dapat mengurangi orde-orde harmonisa lainnya. Selain itu, filter harmonisa pasif juga bisa meningkatkan nilai power factor (PF) yang lebih tinggi.

Kata kunci: total distorsi harmonisa, analisis aliran beban harmonisa, filter pasif, variable frequency drive

PREFACE

Alhamdulillah, all praise and gratitude belongs to Allah Subhanahu wa Ta'ala the Almighty, that has given power, grace, pleasure, and guidance so this bachelor thesis can be completed according on scheduled time. In its completion, there are many help has been given to me from extraordinary great people, those people are:

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2. Mr. Dr. Eng. M. Badrus Zaman, S.T., M.T., as Head Department of Marine Engineering, Faculty of Marine Technology, ITS.
3. Mr. Indra Ranu Kusuma, S.T., M.Sc., and Mr. Ir. Sardono Sarwito M.Sc., both my supervisors of this bachelor thesis.
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Finally, I hope this bachelor thesis report can be useful for the readers and for me to finish my bachelor degree. My apologize for the readers if there is any mistake in the making, writing, grammar, and so on in this thesis. In the further I will always improve myself and may we all become a person who is always blessed and give many benefits to the others. Aamiin.

Surabaya, July 2016

Faisal Muhammad Satrio

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CHAPTER 1
INTRODUCTION

1.1 Background

In a ship, there is a system that is important so that the ship can move, one of which is the propulsion system. The use of diesel engine propulsion system is a conventional system. Diesel motor paired with a shaft as a connector between the diesel engine with a propeller.

However, along with developments in technology, ship propulsion systems have many different types of propulsion systems. One of them using an electric propulsion system using electric motors. There are 2 types of electric motors that will be used for research of electric propulsion system, there are; DC motors and three-phase induction motor.

This thesis will discuss electric propulsion system on the tanker using a three-phase induction motor as a replacement for conventional propulsion systems. However, in its application, there is interference on frequency of the electricity generated by the electric propulsion system. The quality and security of its voltage supply is crucial to the safety of any marine vessel. With the increasing use of AC and DC electric drives for applications such as electric propulsion, this has become an even greater issue. Electric propulsion provides significant benefits, such as lower running costs, less maintenance, reduced manpower, greater redundancy, lower emissions, improved maneuverability (with podded or azimuth type propulsors) and increased cargo carrying capabilities. But by drawing current in a non-linear or non-sinusoidal manner, electric propulsion can introduce excessive levels of both current and voltage harmonics. [1]

One of them is frequency defects or harmonic due to the use of power electronic converter. Electronic power converter has functions to control the speed of three-phase induction motor. As a result of frequency defects or harmonic itself could damage equipment that uses electrical energy that is connected directly to the electrical system on board. The input current to a static power converter has, in general, a high harmonic content due to the wav the current is switched (chopped)from phase to phase. Harmonic currents are important because they cause distortion of the supply voltage waveform which

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[1] I. C. Evans, A. H. Hoevenaars, P.Eng, Member, IEEE. Meeting Harmonic Limits on Marine Vessels. 2007

may result in the malfunction and additional heating of other equipment connected to the supply system. The size and frequencies of the harmonic currents and voltages depend on the converter type, the pulse number and method of control (e.g. synchroconverter, cycloconverter or PWM).

To reduce the problem of defective frequency wave or harmonic, one of them can be solved by installing a passive harmonic filter. Passive harmonic filter serves to repair defects caused waves of components or other variables that could disrupt the working frequency.

1.2 Problem Statement

The passive harmonic filter design can overcome the problem of frequency wave defects that caused from using power electronic converters that are used to control the speed of three-phase induction motor in the propulsion system on board, then some induction motor load (e.g. exhaust and supply fan), and another intermittent load.

Based on the explanation above, the main problem will be discussed is as followed;

1. How much harmonic on ship electrical system before installation of Passive Harmonic Filter?
2. How to configure Passive Harmonic Filter appropriately to overcome the harmonic on ship electrical system?
3. How much harmonic on ship electrical system after installation of Passive Harmonic Filter?

1.3 Problem Limitations

In order to meet expected results, this thesis need to have limitations so the aim of this thesis can be achieved on time, the limitations are as follows;

1. This thesis is focusing on how to calculate needed of Passive Harmonic Filter in the tanker ship due to harmonic on ship electrical system.
2. Cost and economic factor are not included.
3. Changes to the design, EPM value, and ship structure are not discussed here in this thesis.

1.4 Objectives

The objectives of this thesis are;

1. To obtain value of harmonic before installation of Passive Harmonic Filter.

2. To obtain an appropriate design of Passive Harmonic Filter.
3. To obtain value of harmonic after installation of Passive Harmonic Filter.

1.5 Benefits

The benefits of this thesis are;

1. The data that have been obtained can be used as a reference in developing the Electric Propulsion System on ship.
2. Develop a design of the Passive Harmonic Filter for Electric Propulsion System.

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CHAPTER 2
LITERATURE STUDY

2.1 Overview

2.1.1 Harmonic

Generally harmonic frequencies are integer multiples (e.g. 3, 5, 7, 11, 13, 15, etc.) of the fundamental (supply) frequency. Hence, a 7th harmonic in a 50 Hz a.c. voltage has a frequency of 350 Hz and an 11th has a frequency of 550 Hz. Harmonic amplitudes are roughly the reciprocal of the harmonic number, i.e. 20% (1/5) for the 5th, 14.3% for the 7th, 9.1% for the 11th, etc. The particular shape of the resulting supply voltage will depend on harmonic currents causing additional harmonic voltages in the supply reactance (inductive and/or capacitive). [2]

Some harmonics are eliminated by careful system design e.g. by adding more circuit inductance, using phase-shifting transformers (star-star and star-delta) and increasing the converter pulse number. The 30^{o} phase-shifted transformers effectively double the current pulses drawn by the motor so a 6-pulse converter system appears to be 12 pulse as viewed from the supply point. See example in Figure 2. 1.

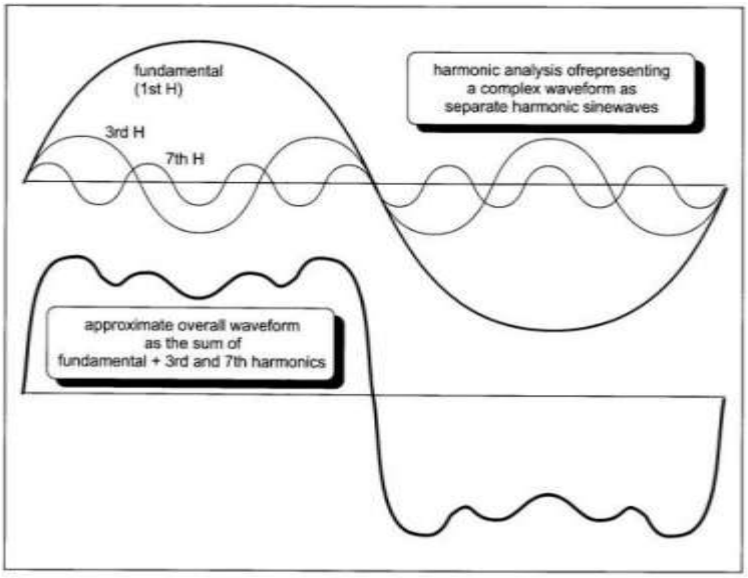

Figure 2. 1. Harmonic analysis of waveforms. [2]

[2] Dennis T. Hall B.A. PRACTICAL MARINE ELECTRICAL KNOWLEDGE. 1984.

For a generator sinusoidal a.c. voltage waveform with identical positive and negative shapes, all even numbered harmonics are cancelled [3]out. In a three-phase a.c. system, all harmonics that are a multiple of three are also automatically cancelled. That leaves harmonic numbers of 5^{th}, 7^{th}, 11^{th}, 13^{th}, 17^{th}.etc. as potential problems. For a pair of six-pulse synchroconverters supplied by a pair of phase-shifted transformers the significant harmonic problem is reduced to the 5^{th}, 11^{th} and 17^{th}. [2]

The harmonic content of the a.c. input to a synchroconverter also has components that are related to the motor operating frequency. The d.c. link reactor coil reduces the ripple in the link current so that the effect on the a.c. supply side is reduced.

There are also some effects effects of Harmonics, there are as follows;

Table 2. 1. Some Effects of Harmonics [3]

At	Effects
Circuit Breakers	Malfunction
Capacitor banks	Overheating Insulation Breakdown Failure of internal fuses
Protection Equipment	False tripping No tripping
Measuring devices	Wrong measurements
Transformers, reactors	Overheating
Motors	Increased noise level Overheating Additional vibrations
Telephones	Noise with the respective harmonic frequency
Lines	Overheating
Electronic Devices	Wrong pulses on data transmission Over-/undervoltage Flickering screens
Incandescent lamps	Reduced lifetime Flicker

[2] Dennis T. Hall B.A. PRACTICAL MARINE ELECTRICAL KNOWLEDGE. 1984.
[3] Alexander Kusko, Marc T. Thompson. POWER QUALITY in ELECTRICAL SYSTEMS. 2007

The effects of harmonics are not only that, there are also several technical impacts [4] as follows;

- Overloads on the distribution system due to the increase in rms current.
- Overload on the neutral conductor due to the summing of the third and its multiple-order harmonics created by single-phase loads.
- Overloads, vibrations, and premature aging of generators, transformers, motors, and so on, and capacitor of power factor (PF) correction equipment.
- Distortion of the supply voltage capable og disturbing sensitive loads
- Disturbances on communication networks and telephone lines.

2.2 Harmonic Filter

To minimize the size of voltage distortion it is necessary to connect *filters* which are *tuned* to the troublesome harmonics. The filters are combination sets of inductance (L) and capacitance (C) each resonantly tuned to a particular frequency in a series/parallel circuit. Additionally, some resistance (R) is included to act as a harmonic current limiting (damping) effect. [2]

The simplest way to view the overall system is to consider that the converter injects harmonics while the filter absorbs them. Filtering is not perfect over the variable frequency range so the harmonic problem is not completely solved but is minimized.

Practical harmonic installations in power systems are physically large and will create power losses and heat in the components.

2.2.1 Passive Filter

Passive filter is a series of parallel or in series between the components of the inductor (L) and capacitor (C). The filter circuit can be tuned to a specific frequency where the impedance of the inductor to be equal to the impedance of the capacitor. The effectiveness of filters work

[2] Dennis T. Hall B.A. PRACTICAL MARINE ELECTRICAL KNOWLEDGE. 1984.
[4] Abdelhay A. Sallam, Om P. Malik. Electric Distribution Systems. 2012.

is determined by changes in electrical network impedance, and accurate study are required prior to filter installation. [5]

Parallel Circuit Filter

$$|Z| = \frac{X_L X_C}{X_L + X_C}$$

$$X_L = j\omega L \qquad X_C = -j\frac{1}{\omega C}$$

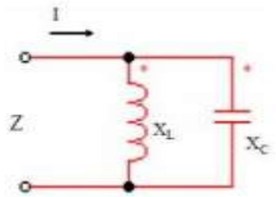

Figure 2. 2. Parallel Circuit Filter. [5]

If given a voltage source with the resonance frequency, Fr,
where |XL| = |XC|
XL + XC = 0, so that;
- Very large impedance Z
- The current I approaches zero

Series Circuit Filter

$$Z = X_L + X_C$$

$$X_L = j\omega L \qquad X_C = -j\frac{1}{\omega C}$$

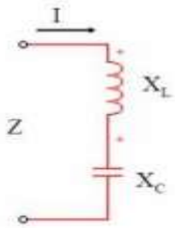

Figure 2. 3. Series Circuit Filter. [5]

If given a voltage source with the resonance frequency, Fr,
where | XL | = | XC |
XL + XC = 0, so that;
- Impedance Z = 0
- Current I have a greater value

---

[5] Suryono, Sutedjo, M. Zaenal Efendi, Andrias Ade, Sigit Prasetya. Filter Pasif Untuk Mereduksi dan Memanfaatkan Harmonisa Ke-5 dan 7 pada Beban Konverter 6 Pulsa Sebagai Sumber Energi Dengan Menggunakan Full Bridge DC-DC Converter dan Inverter.

And installation of passive filters as in Figure 2. 4, there are two filters (filter harmonics 5th and 7th harmonic filter).

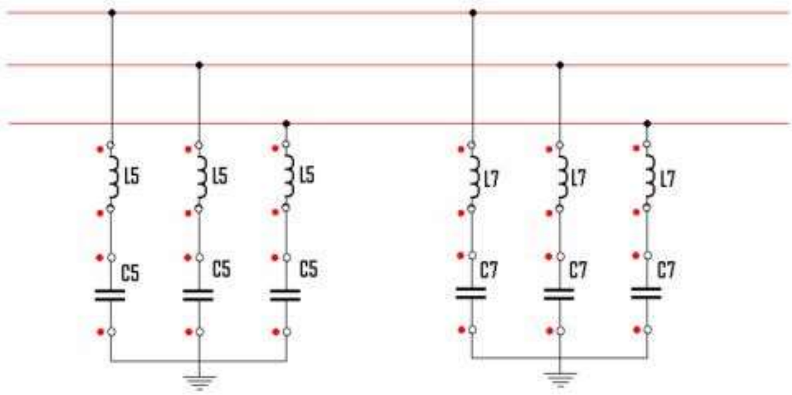

Figure 2. 4. a 3-Phase Passive Filter Circuit System. [5]

Because it uses the three-phase source, then each phase is established with passive harmonic filter circuits.

2.3 Harmonic Limit Standard

2.3.1 Classification Rules

DNV GL Rules I, Part 1, Chapter 3 - Electrical Installations. [6]

- Section 1 – General Requirements and Guidance

  F.2.1

  "In systems without substantial static converter load and supplied by synchronous generators, the total voltage harmonic distortion shall not exceed 5 %."

  F.2.2

  "In systems fed by static converters, and systems in which the static converter load predominates, for single harmonics in permanence the limit values indicated in Fig. 1.1 apply.

  The total harmonic distortion shall not exceed 8 %."

---

[5] Suryono, Sutedjo, M. Zaenal Efendi, Andrias Ade, Sigit Prasetya. Filter Pasif Untuk Mereduksi dan Memanfaatkan Harmonisa Ke-5 dan 7 pada Beban Konverter 6 Pulsa Sebagai Sumber Energi Dengan Menggunakan Full Bridge DC-DC Converter dan Inverter.

[6] DNV GL SE. Electrical Installations (I-1-3). 2014.

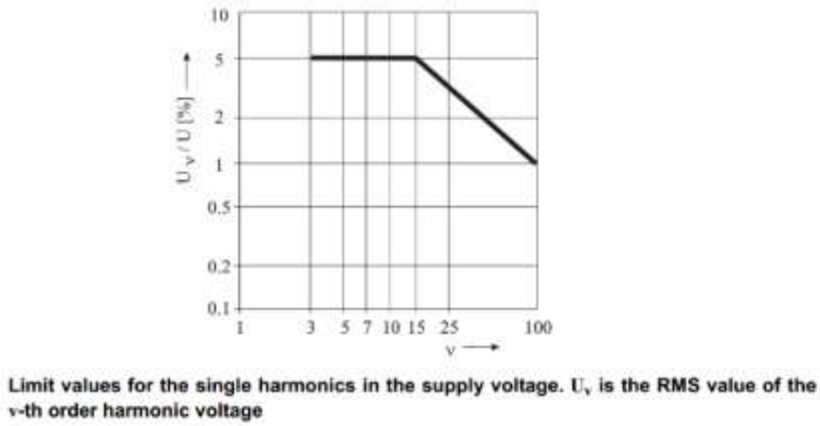

Figure 2. 5. Harmonic Value based on harmonic order [6]

- Section 3 – Power Supply Installations

B.2.2 Waveform

"The waveform of the line-to-line no-load voltage shall be as close as possible to sinusoidal. The deviation from a sinusoidal fundamental shall at no time exceed 5 % relative to the peak value of the fundamental. The RMS values of the phase voltages shall not differ from each other by more than 0.5 % under balanced load conditions.

If the star points of generators running in parallel are earthed, the waveforms of the phase voltages should coincide. It is to ensure that the transient current due to harmonics in the starpoint connection does not exceed 20 % of the rated current of the machine with the lowest output."

- Section 13 - Additional Rules for Electrical Main Propulsion Plants

B.3.1

"The effects of the harmonics of currents and voltages shall be taken into consideration for the design of the propulsion motors."

C.5 Filter Circuits

C.5.1

"If filter circuits are used to reduce the harmonics, these circuits must be protected against overload and short circuit."

C.5.2

"Filters shall be monitored for failure."

[6] DNV GL SE. Electrical Installations (I-1-3). 2014.

C.5.3

"The operating instructions shall document which propulsion settings and generator combinations are admissible after failure of one or all of the filters. This shall be verified by means of a THD measurement."

C.5.4

"Filters shall function properly in all propulsion settings and grid configurations and shall not lead to increases in voltage or current. This shall be verified through measurements during the sea trial."

- Section 20 – Electrical Equipment

A.1.13 Operation in network with semiconductor converters

"Electric machines operating in networks containing semiconductor converters shall be designed for the expected harmonics of the system. A sufficient reserve shall be considered for the temperature rise, compared with a sinoidal load."

C.4.3

"In systems with high levels of harmonics, capacitors shall be protected against overloading by the use of series inductors and/or the selection of a higher capacitor voltage rating."

2.4 Passive Filter Design with ETAP Software

This thesis will use a software ETAP to get the simulation and conclusion for the result. Before designing a passive harmonic filter, it needs to analyze Harmonic Load Flow from ship electrical system itself. The process of Harmonic Load Flow Analysis and Designing Passive Filter with ETAP [7] will be explained below.

2.4.1 Harmonic Load Flow Analysis

To generate a Harmonic Load Flow Analysis, a whole ship electrical network system must be established on ETAP diagram. After established, then fill required harmonic current source specification. This harmonic

[7] Filter Sizing Tutorial Video. Web. etap.com/resources. 2010.

source comes from a non-linear source. In this case harmonic are come from variable frequency drive.

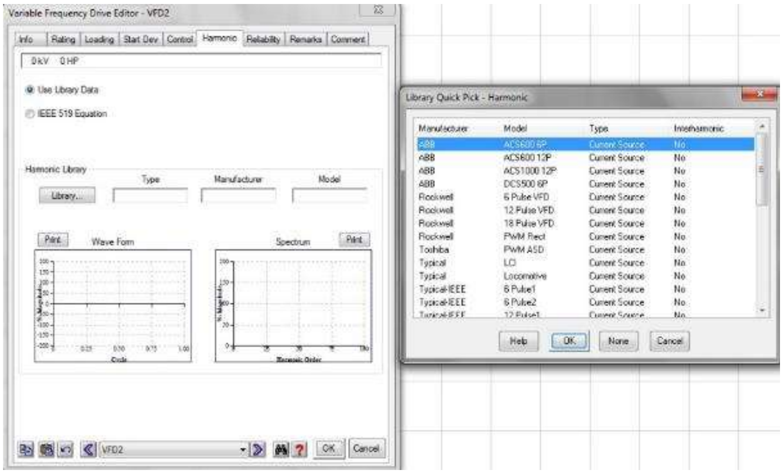

Figure 2. 6. Harmonic Library for Variable Frequency Drive [8]

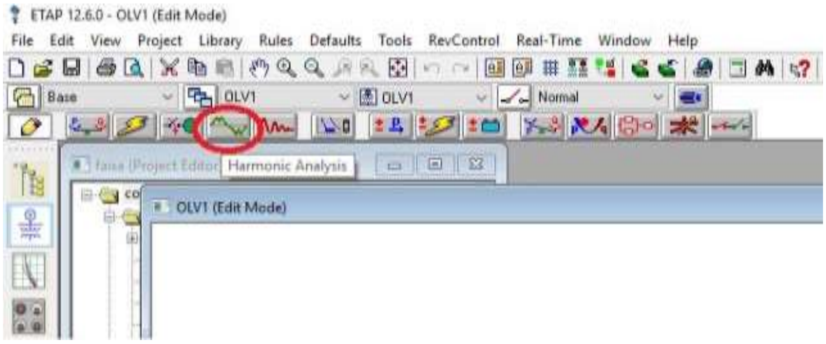

Figure 2. 7. Harmonic Analysis Mode [8]

Then, do harmonic load flow analysis.

Do harmonic analysis for every harmonic order. Before continuing to next order, the harmonic distortion data need to be collected so the filter design are specific to certain order.

[8] ETAP Version 12.6.0

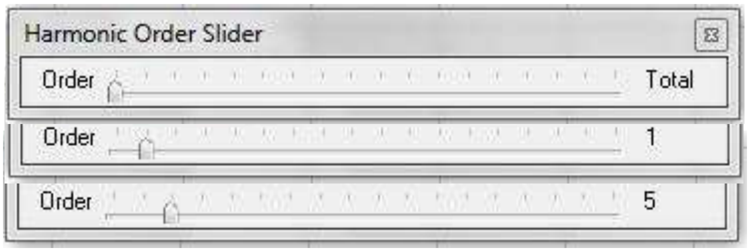

Figure 2. 8. Harmonic Order Slider [8]

2.4.2 Passive Harmonic Filter Design

After harmonic distortion data from all harmonic orders are collected, a Passive Harmonic Filter can be designed.

First, back to edit mode.

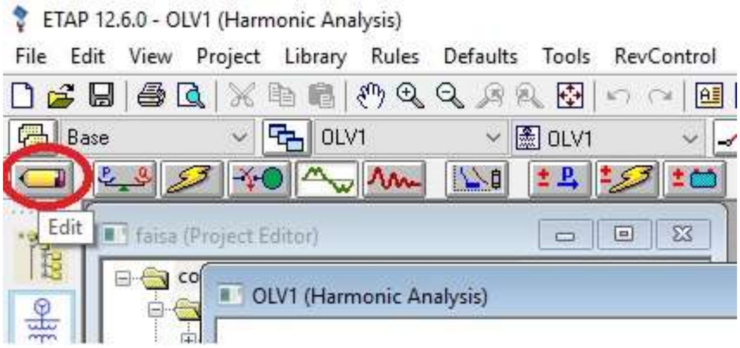

Figure 2. 9. Edit Mode [8]

Then put the harmonic filter on the bus bar that have a significantly large number of harmonic distortion that can occur another electrical machines or electrical equipment.

Figure 2. 10. Passive Harmonic Filter Symbol [8]

[8] ETAP Version 12.6.0

After placing the filter, then determine filter type, then size the filter for required harmonic order, fill harmonic current, fill Existing and Desired Power Factor (PF), and fill Load Factor on Figure 2. 11.
Then, click size filter and ETAP will automatically calculate capacitor and inductor that will be substituted to filter by click substitute.

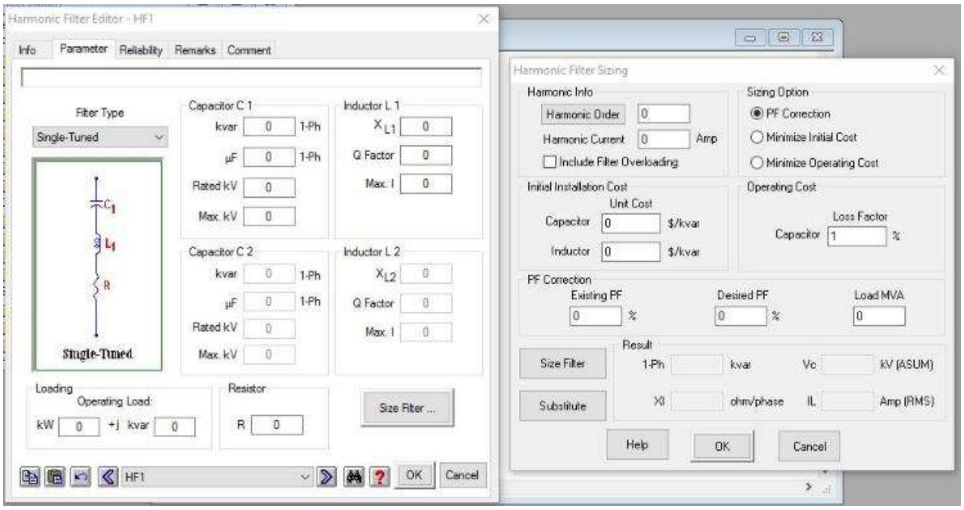

Figure 2. 11. Passive Harmonic Filter editor [8]

But the harmonic order were not exactly the value of its harmonic frequency integer (e.g. 5th order harmonic value are not exactly 5). The tuning order to be applied in sizing the single-tuned filter are shown in Table 2. 2.

Table 2. 2. Tuning Orders in an applied tuning factor [9]

Order	5th	7th	9th	11th
Tuning	4.813	6.734	8.663	10.59
Order	13th	15th	17th	19th
Tuning	12.51	14.44	16.36	18.29

---

[8] ETAP Version 12.6.0
[9] Young-Sik Cho & Hanju Cha. Single-tuned Passive Harmonic Filter Design Considering Variances of Tuning and Quality Factor. 2011.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 General

Methodology should be done to accomplish the objectives on this thesis. A good methodology became one of the most important points. This methodology will explain what processes should be done, starts from the background and the problem statement, the data what should have, then how the data is processed, until purpose of this thesis.

3.2 Methodology Flowchart

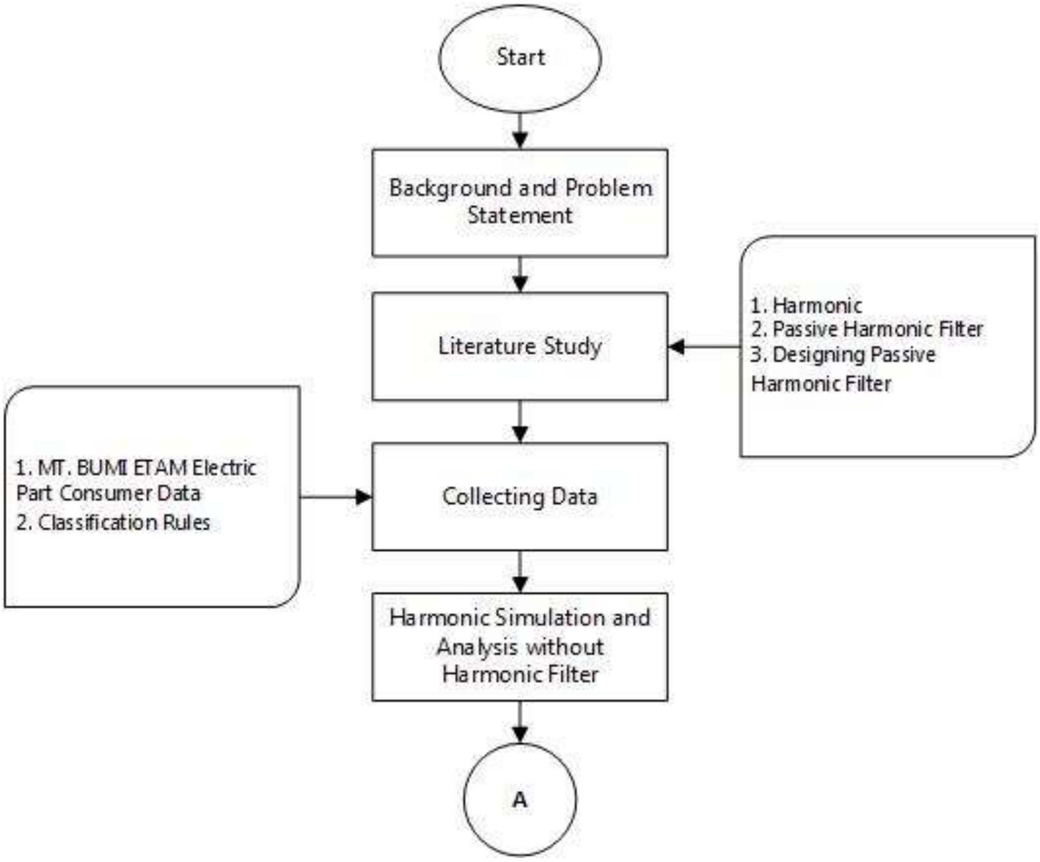

Figure 3. 1. Methodology Flowchart 1

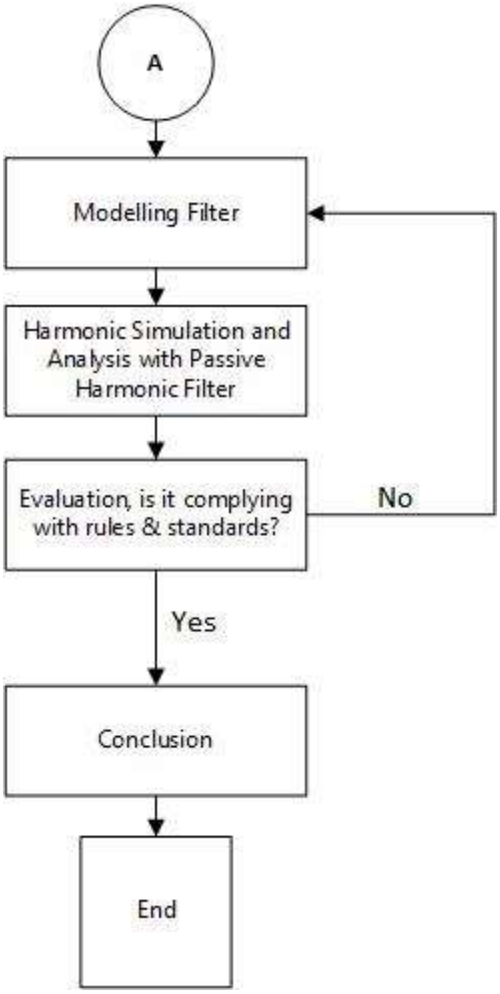

Figure 3. 2. Methodology Flowchart 2

3.3 Background and Problem Statement

This stage is an early stage to construct the thesis, questions and problems are being prepared specifically in order to determine the specific objectives of this thesis. The content of the thesis is to overcome the statement of the problems mentioned earlier and it will be done by collect some information about the problems. Therefore, the purpose of this thesis can be understood in this stage.

3.4 Literature Study

Right after the problems is raised, a literature study is performed. In this stage, literature will be used to connect the problems with existing theories and facts from various sources. The study of literature is done by reading papers, journals, thesis, media and literature books that relates and able to support this thesis.

3.5 Collecting Data

After literature study which support the thesis has been done, collecting data is being performed. Data collection is done by gather information to develop the design, most of data is available from the ship design data, classification rules, standards, propulsion motor, and filter specification. The data which may support this thesis is the engine specification, electric motor for propulsion unit, auxiliary unit specification, filter specification, classification and standards.

3.6 Harmonic Simulation & Analysis without Harmonic Filter

This stage is about create and constructing ship electrical network system, many data from power source to power output have to be constructed due to preparing simulation for Harmonic Load Flow Analysis before Designing a Passive Harmonic Filter. Then do a simulation to obtain a data from ship electrical network system about how much harmonic and distortion that happen on the electrical system. Then the obtained data is required to be analyzed for Designing a Passive Harmonic Filter.

3.7 Modelling Filter

After getting result of simulation, it requires to determine harmonic current source specification that came from non-linear source. This thesis is specifically directing this non-linear source to power electronic converter that in this case are using variable frequency drive. Then do a harmonic load flow analysis, do load flow simulation of every harmonic order. The last is collect harmonic distortion data of all harmonic order

This stage can be done by collecting accurate data from stage 6. This stage is designing required passive harmonic filters for certain harmonic orders. This are about determine filter type, size the filter for required harmonic order, then the rest of it let ETAP automatically calculate capacitor and inductor that will be substituted to desired passive filter.

3.8 Harmonic Simulation & Analysis with Passive Harmonic Filter

After modelling filter, this stage is similar to Harmonic Simulation & Analysis step. But, the difference is while running the simulation, the ship electrical network system is already fitted with passive filter that will reduce the harmonic and distortion that will be compared to simulation without installing a passive filter.

3.9 Evaluation, is it complying with rules & standards?

This is the important point of this thesis, evaluation from the analysis result of installing and simulate passive filter on the ship electrical network system must be can reduce the harmonic and distortion on the system, and complying with rules and standards.

3.10 Conclusion

The result, this stage is last stage to end this thesis, questions and problems are answered specifically in order to meet the specific objectives of this thesis. The conclusion of the thesis is to fulfill the statement of the problems mentioned earlier and it will be done by collect design data of passive harmonic filter that are designed and comply with stage 9. Therefore, the result of this thesis can be used as a reference to application of ship that using electric propulsion system.

CHAPTER 4
DISCUSSION AND DATA ANALYSIS

4.1 General

In this chapter, the data analysis and discussion, there are several steps that need to be explained. The design process of the passive harmonic filter that will be applied to electrical system on the ship. The data required to support the process of this thesis are MT. BUMI ETAM electrical system include the electrical system network, Main Switch Board network, specific electric consumer for every condition (e.g. sailing, maneuvering, and so on). This is the initial stage to establish the ship electrical network in ETAP software to do a simulation. Then the result from the simulation will be used to design passive harmonic filter.

After getting the result of simulation, this first result data are not equipped with a harmonic filter. So, the harmonic value must be have a high value due to the use of variable frequency drive. The next stage after designing and installing passive harmonic filter, a simulation have to be done to know the result after applying a passive harmonic filter with a harmonic value that occur in the ship. This data will be compared by using a chart to identify the harmonic value of each bus and branch in before and after installing the passive harmonic filter.

Goal of this thesis is to reduce the harmonic value (THD) according to classification requirements that the THD value need to be lower than 5%.

4.2 Data collection

4.2.1 Ship Description

Ship description is a general data such as ship particular, ship propulsion systems, machinery and electrical system, electrical consumen, electrical power consumer for each conditions.

Name	: MT. BUMI ETAM	
Type	: Product Oil Tanker	
GT	: 1170	ton
Lpp	: 66	m
Lwl	: 67,98	m
B	: 12	m
H	: 4,9	m
T	: 4,3	m
Cb	: 0,6966	

Cp : 0,7001
Cm : 0,9827
Vs : 11 knots
Cb WL : 0,6889
Radius : 200 mil
ρ water: 1,025 ton/m^3
Route : Balikpapan - Jakarta

4.2.2 Propulsion Motors

In the beginning, this ship was used to be designed using a diesel engine as propulsion motor. The diesel engine specification are as follows;

Table 4. 1. Diesel Engine Data for Past-Design of Propulsion Motor

WARTSILA 4520	
Power (kW)	800
RPM	1000
SFOC (g/kWh)	197
Dimension (L x W x	2510 x 1483 x 2073
Weight (ton)	7,2
Fuel	HFO/MDF

When changing from diesel engine into an electric 3-Phase induction motor then some equipment's that using electrical power to support the diesel engine are mostly eliminated. Those eliminated equipment's are as follows;

1. HFO Separator
2. HFO Pre-Heater
3. HFO Transfer Pump
4. HFO Stand-by Pump
5. LO Transfer Pump
6. LO Separator Unit
7. LO Pre-Heater Separator
8. LT/HT Standby Pump

The new propulsion motor are using 3-Phase Induction Motor. The specification are as follows;

Table 4. 2. A 3-Phase Induction Motor Data for Present-Design of Propulsion Motor

ABB M3BP 450LC 6	
Power (kW)	800
RPM	994
Current I_N (Amp)	1469
Efficiency ($^1/_2$ Load – Full	96,8 %
Torque T_N (Nm)	7682
Weight (ton)	4,8

To control the speed of this electric 3-phase induction motor, the Variable Frequency Drive (VFD) are needed to be installed on the motor. Selected VFD for this drive are as follows;

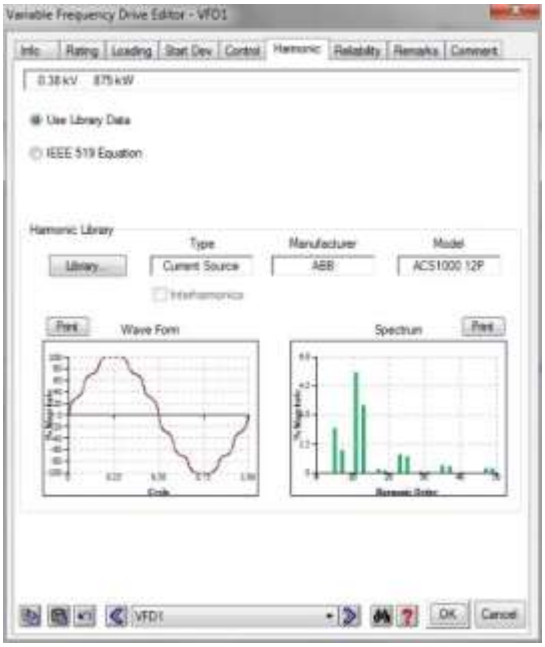

Figure 4. 1. Variable Frequency Drive Data

4.2.3 Generator

The propulsion motor is now needed to be supplied by electricity power. Electricity in this ship were generated by a diesel generator. The past designed generators must be replaced due to increase of electric power consumers, especially by the propulsion motor.

Total power consumption on this ship before and after installed 3-Phase induction motor, the value are taken from highest power consumption while ship on various operating condition;

- Before :- 56 kW (On Sailing condition)
  - 66,6 kW (On Maneuvering condition)
  - 137,8 kW (On Cargo Handling condition)
  - 65,1 kW (On Port condition)
- After :- 708,2 kW (On Sailing condition)
  - 708,3 kW (On Maneuvering condition)
  - 96,9 kW (On Cargo Handling condition)
  - 57,7 kW (On Port condition)

Past-design generators are only use 2 diesel generators with specification as follows;

Table 4. 3. Diesel Generator of Past-Design

Caterpillar 4.4	
Power (kW)	86
RPM	1500
Frequency (Hz)	50
Total set (Unit)	2

Total generated power from this generator are;

- Power x Set = 86 x 2
  = 172 kW

With new total electric power consumption that increased by electric propulsion system, Present-design generators are upgraded and added some small generators due to significant power consumption on operating conditions;

Table 4. 4. Diesel Generator of Present-Design

CUMMINS C650 D5A	
Power (kW)	409
RPM	1500
Frequency (Hz)	50
Total set (Unit)	2

Total generated power from this generator are;

- Power x Set = 409 x 2
  = 818 kW

This generator are only used for sailing and maneuvering conditions due to high power electric consumption.

Table 4. 5. Diesel Generator of Present-Design.

CUMMINS C125 D5	
Power (kW)	90
RPM	1500
Frequency (Hz)	50
Total set (Unit)	2

Total generated power from this generator are;

- Power x Set = 90 x 2
  = 180 kW

This generator are only used for cargo handling and at port due to small power amount of electric consumption on this condition.

4.3 Establishing and Simulation of Ship Electrical Network on ETAP Software

4.3.1 Establish Ship Electrical Network Data to ETAP Software

The electrical network that will be established on ETAP software are collected from Main Switchboard and each of junction power of each deck as follows;

1. Main Switchboard (Junction Lightning, Steering Gear, and another equipment also included here)
2. Junction Power Engine Room
3. Junction Power Main Deck
4. Junction Power Poop Deck + Boat Deck
5. Junction Power Bridge Deck + Navigation Deck

Ship electrical network simulation data are attached at the end of this thesis.

4.4 Harmonic Analysis & Simulation

After ship electrical network established on ETAP, then harmonic load flow analysis are need to be simulate to get the harmonic value and where did the harmonic happen on the electrical network. The report will show if there is any harmonic value that over the limit that already set. The limit are set to 5% according to 5% as DNV GL Rules standards;

DNV GL Rules I, Part 1, Chapter 3 - Electrical Installations. [6]

- Section 1 – General Requirements and Guidance
  F.2.1

"In systems without substantial static converter load and supplied by synchronous generators, the total voltage harmonic distortion shall not exceed 5 %."

Table 4. 6. Harmonic Load Flow Analysis Report - Sailing Condition, No Harmonic Filter

VTHD (Total Harmonic Distortion) Report - No Filter			
Bus		**Voltage Distortion**	
ID	kV	**Fund.** %	**VTHD** %
Bus Bar 1	0.380	100.00	6.18
Bus Bar II	0.380	100.00	6.18
Bus5	0.380	99.86	6.18
Bus10	0.380	99.97	6.18
Bus11	0.380	99.99	6.18
Bus12	0.380	99.93	6.18
Bus13	0.220	99.71	6.10
Bus14	0.220	99.77	6.14
Cable78~	0.380	99.23	6.39
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

In the other condition; cargo handling and at port, there are no harmonic value after running a simulation. A complete report of the simulation can be found on the attachment of this thesis.

[6] DNV GL SE. *Electrical Installations (I-1-3)*. 2014.

Table 4. 7. Harmonic Load Flow Analysis Report – Maneuvering Condition – No Harmonic Filter

VTHD (Total Harmonic Distortion) Report - No Filter			
Bus		Voltage Distortion	
ID	kV	Fund. %	VTHD %
Bus Bar 1	0.380	100.00	6.18
Bus Bar II	0.380	100.00	6.18
Bus5	0.380	99.54	6.20
Bus10	0.380	99.98	6.17
Bus11	0.380	99.99	6.18
Bus12	0.380	99.93	6.18
Bus13	0.220	99.71	6.10
Bus14	0.220	99.77	6.14
Cable78~	0.380	99.23	6.39
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

4.5 Modelling Filter

There are 6 types of harmonic filter that provided by ETAP. But only the single-tuned harmonic filter can be used for specific harmonic orders. This will have an advantage to minimized the harmonic distortion to meet rules standard.

In order to design a single-tuned harmonic filter, then the specific harmonic order need to determined based on the highest harmonic value.

- **Sailing Condition**

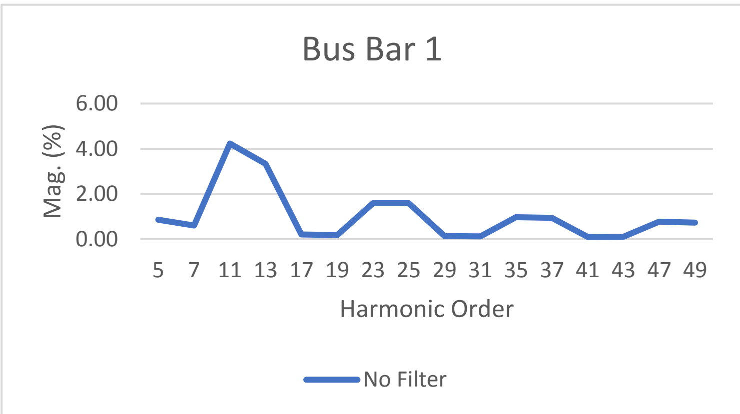

Figure 4. 2. Bus Bar 1 Harmonic Value - Sailing Condition

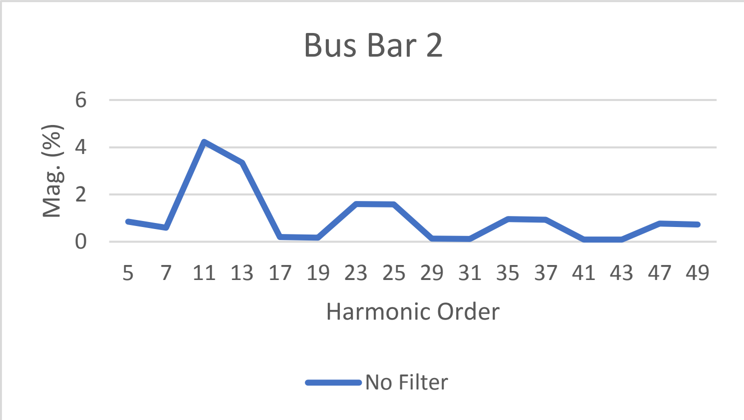

Figure 4. 3. Bus Bar 2 Harmonic Value - Sailing Condition

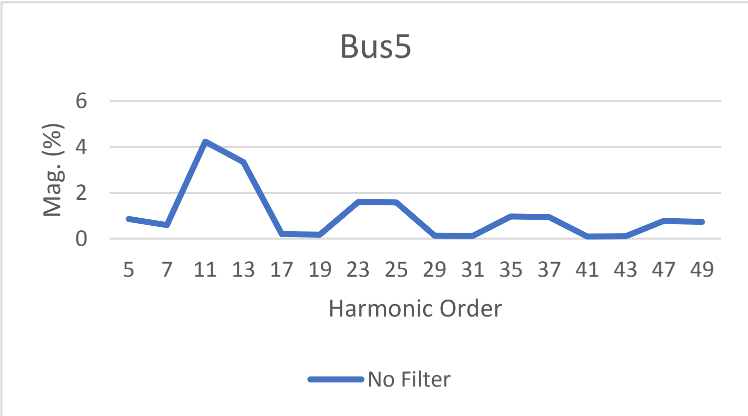

Figure 4. 4. Bus5 Harmonic Value - Sailing Condition

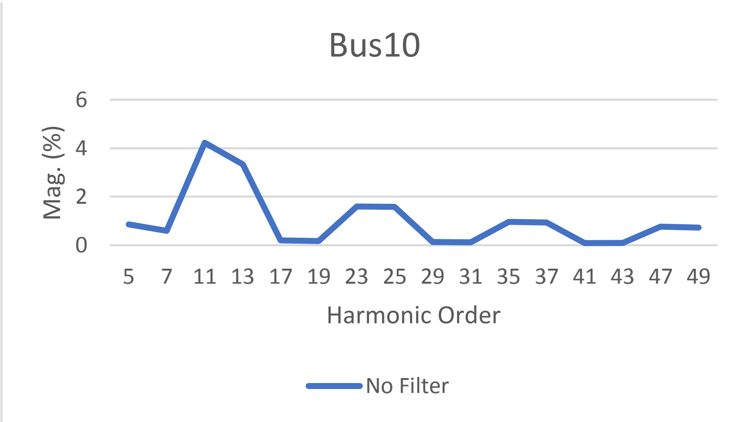

Figure 4. 5. Bus10 Harmonic Value - Sailing Condition

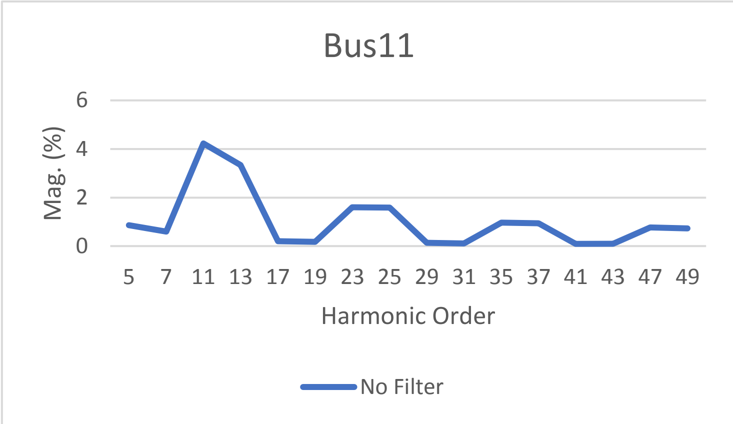

Figure 4. 6. Bus11 Harmonic Value - Sailing Condition

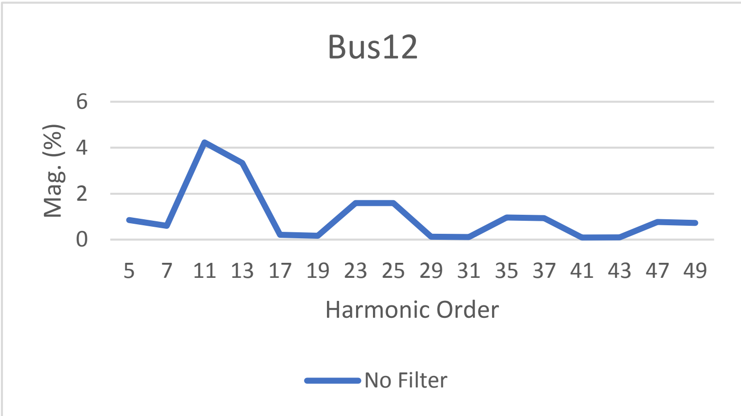

Figure 4. 7. Bus12 Harmonic Value - Sailing Condition

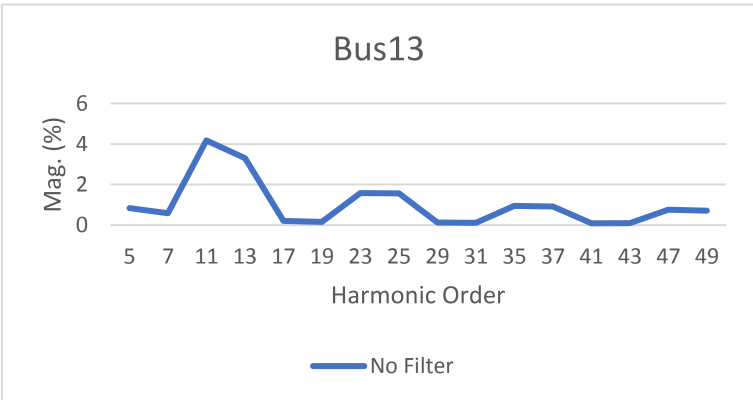

Figure 4. 8. Bus13 Harmonic Value - Sailing Condition

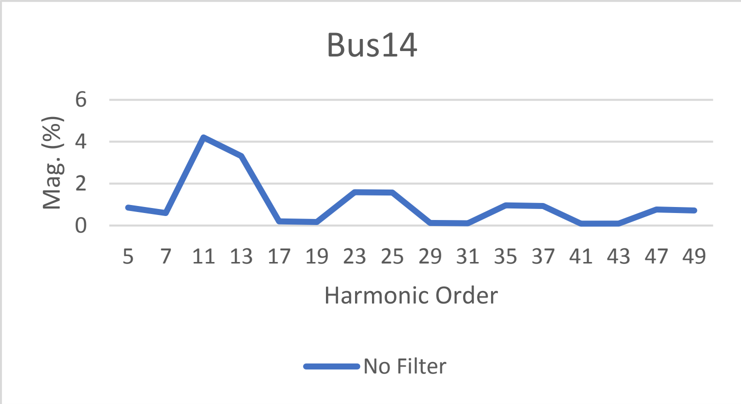

Figure 4. 9. Bus14 Harmonic Value - Sailing Condition

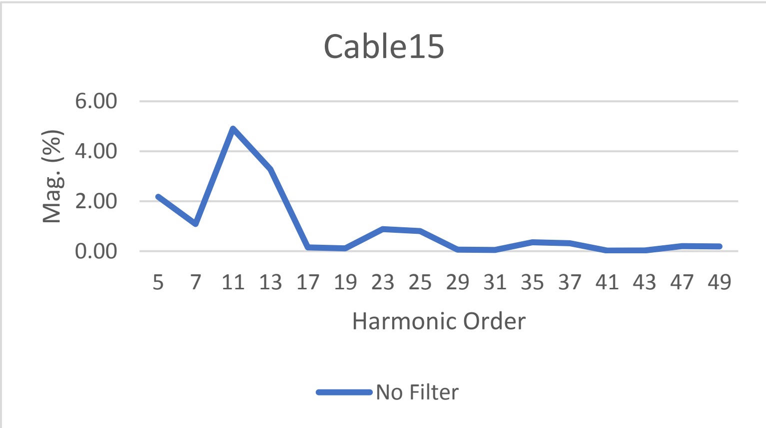

Figure 4. 10. Cable15 Harmonic Value - Sailing Condition

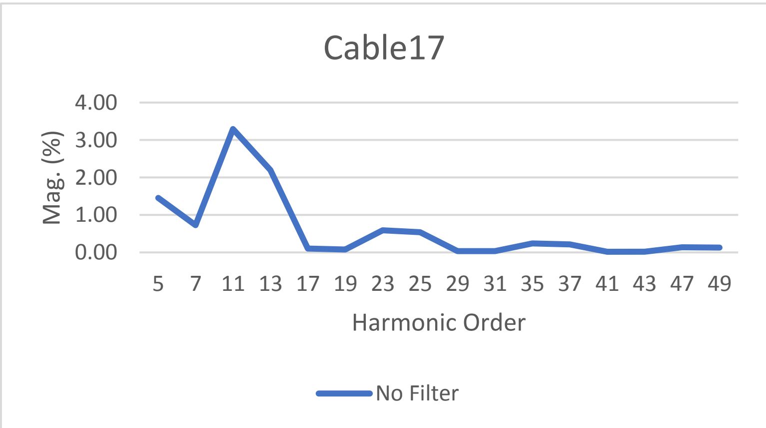

Figure 4. 11. Cable17 Harmonic Value - Sailing Condition

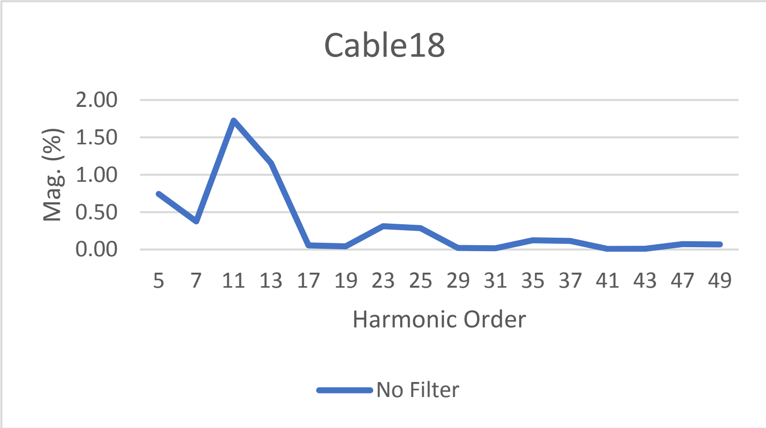

Figure 4. 12. Harmonic Value - Sailing Condition

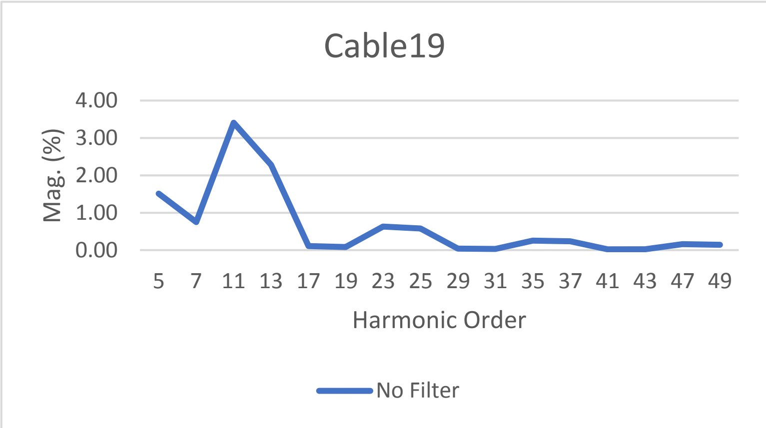

Figure 4. 13. Cable19 Harmonic Value - Sailing Condition

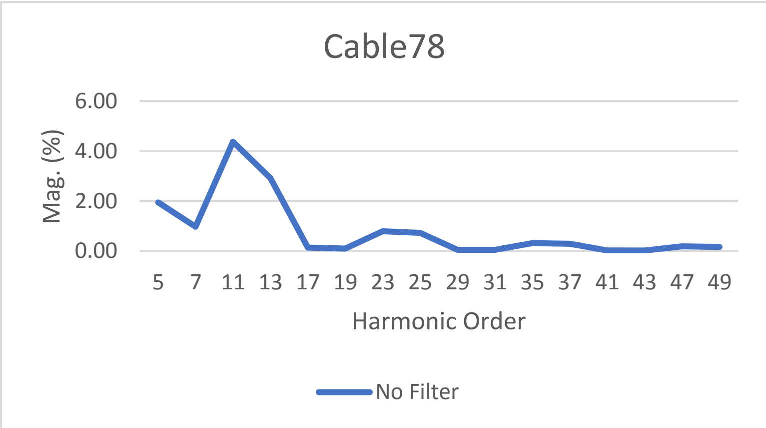

Figure 4. 14. Cable78 Harmonic Value - Sailing Condition

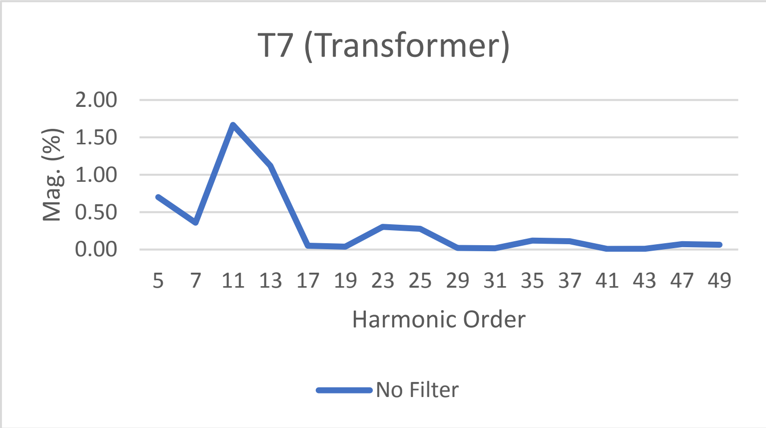

Figure 4. 15. T7 Harmonic Value - Sailing Condition

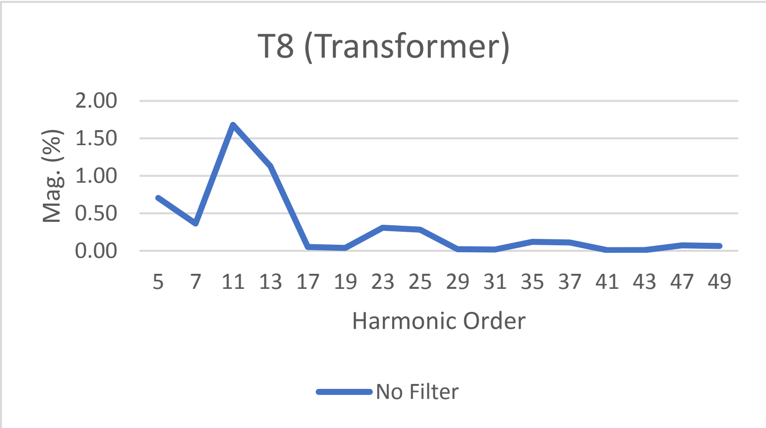

Figure 4. 16. T8 Harmonic Value - Sailing Condition

- **Maneuvering Condition**

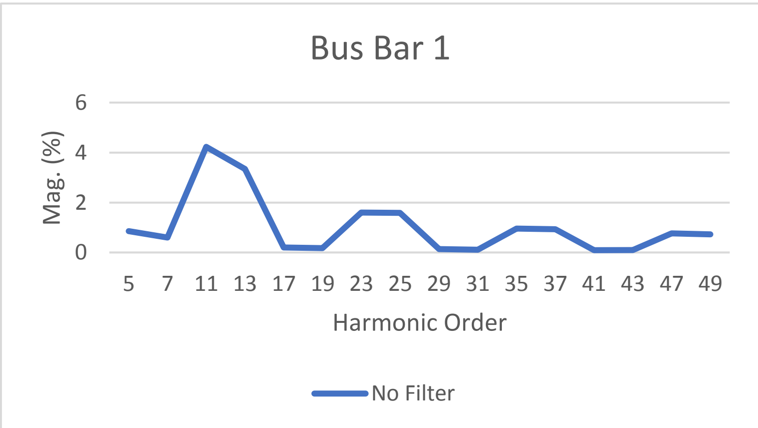

Figure 4. 17. Bus Bar 1 Harmonic Value - Maneuvering Condition

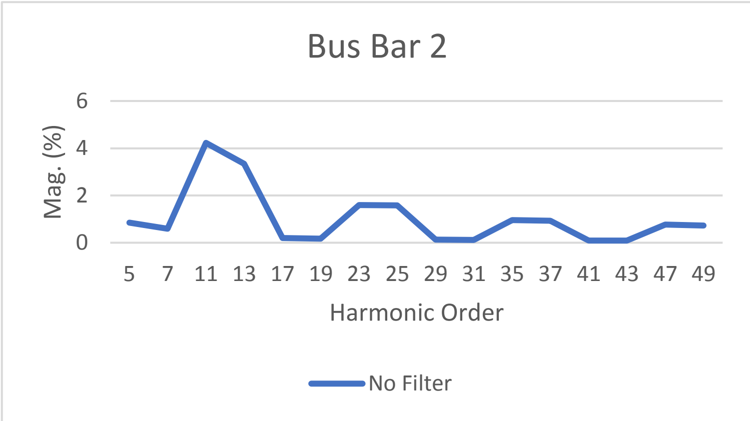

Figure 4. 18. Bus Bar 2 Harmonic Value - Maneuvering Condition

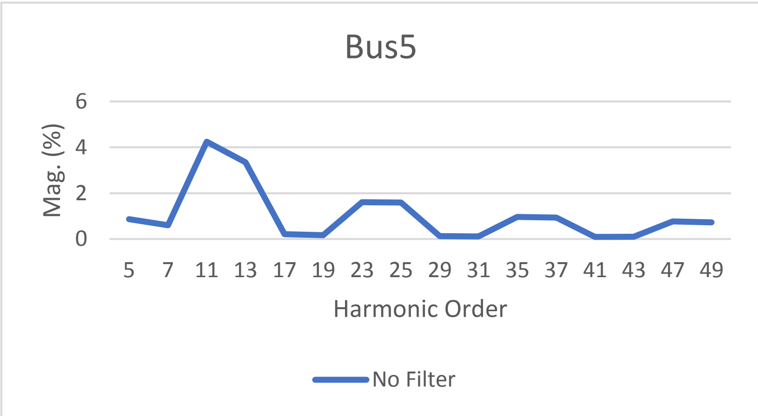

Figure 4. 19. Bus5 Harmonic Value - Maneuvering Condition

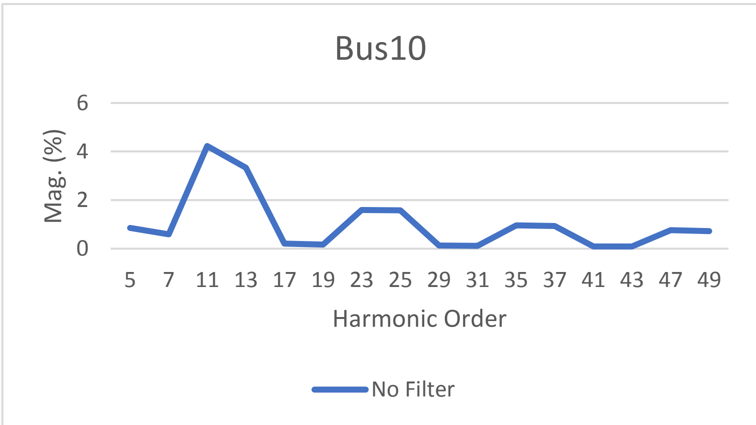

Figure 4. 20. Bus10 Harmonic Value - Maneuvering Condition

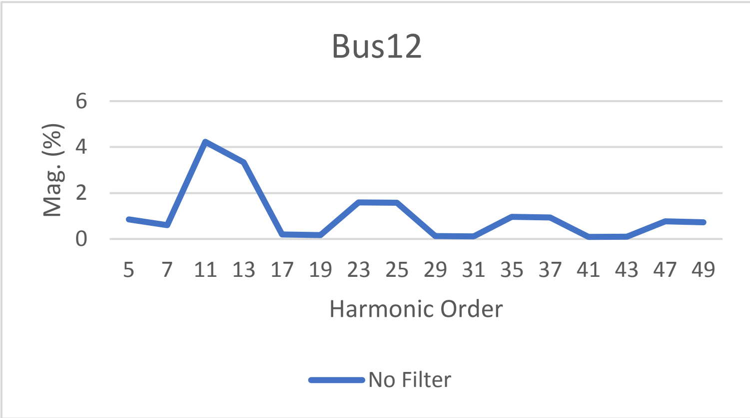

Figure 4. 21. Bus12 Harmonic Value - Maneuvering Condition

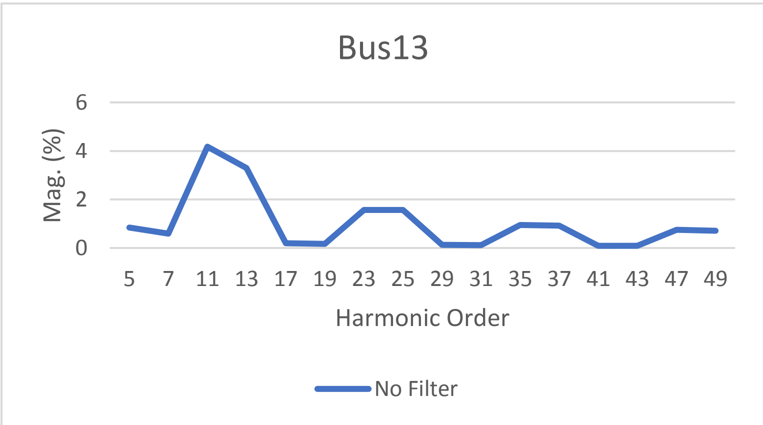

Figure 4. 22. Bus13 Harmonic Value - Maneuvering Condition

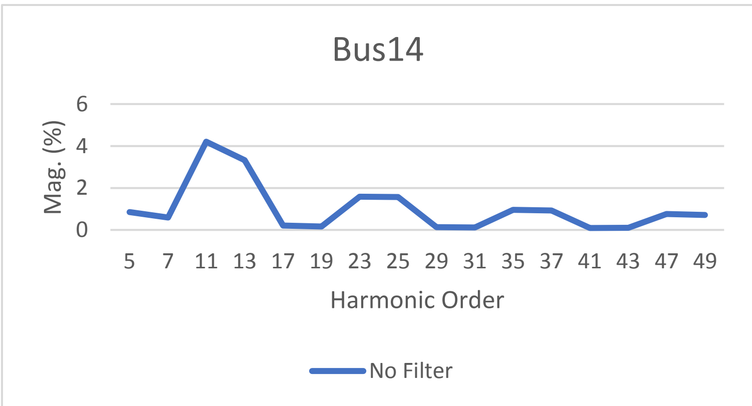

Figure 4. 23. Bus14 Harmonic Value - Maneuvering Condition

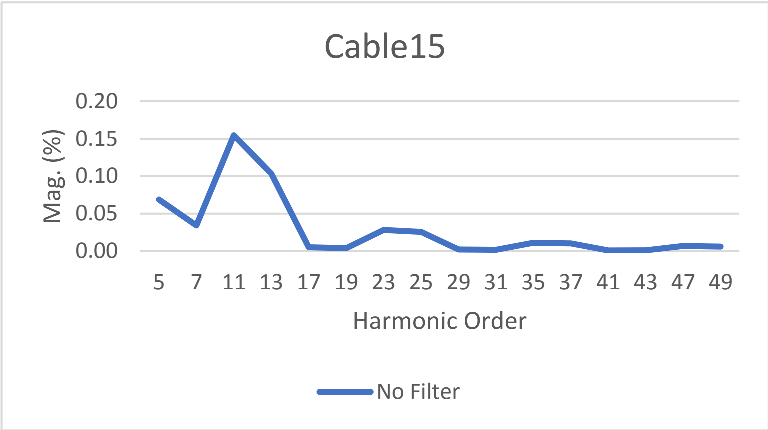

Figure 4. 24. Cable15 Harmonic Value - Maneuvering Condition

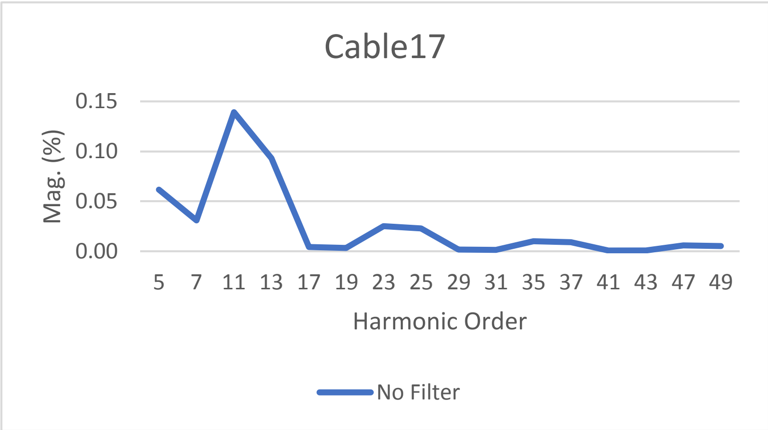

Figure 4. 25. Cable17 Harmonic Value - Maneuvering Condition

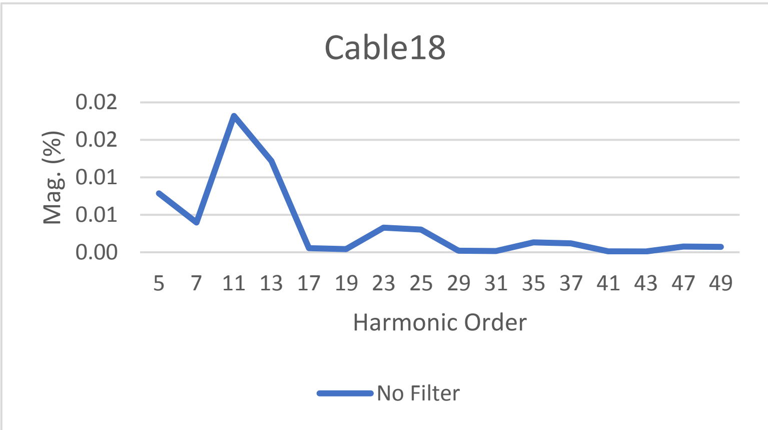

Figure 4. 26. Cable18 Harmonic Value - Maneuvering Condition

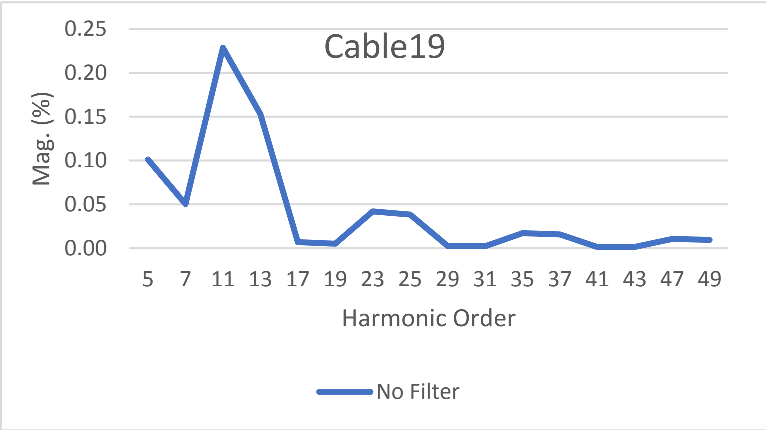

Figure 4. 27. Cable 19 Harmonic Value - Maneuvering Condition

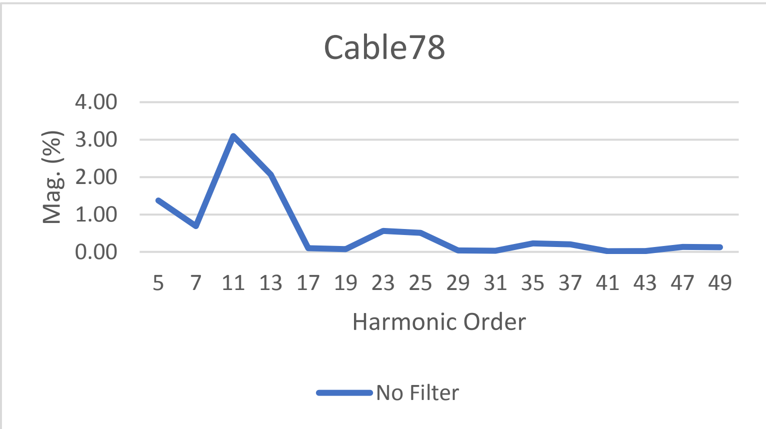

Figure 4. 28. Cable78 Harmonic Value - Maneuvering Condition

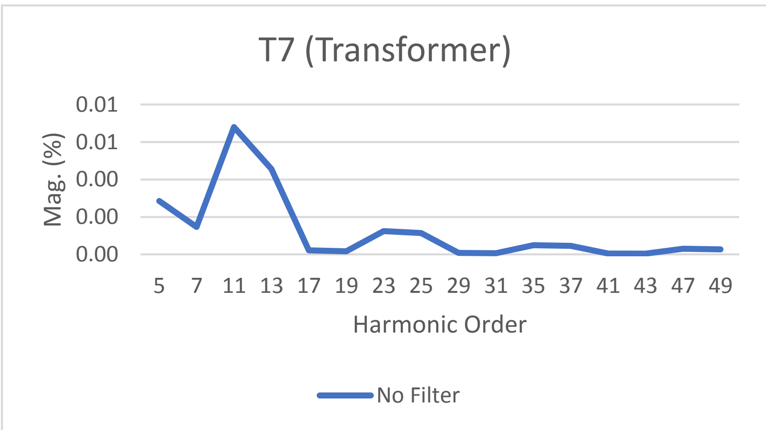

Figure 4. 29. T7 Harmonic Value - Maneuvering Condition

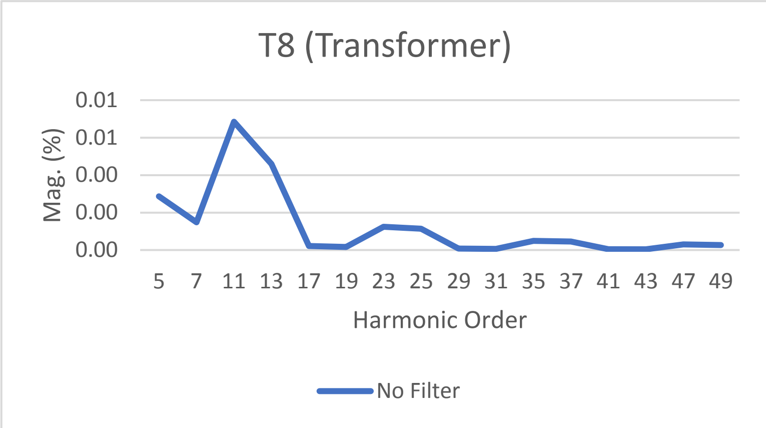

Figure 4. 30. T8 Harmonic Value - Maneuvering Condition

Mag (%) is represent the harmonic current/voltage magnitudes in Amps/Volts on the fundamental current/voltage base.

Based on the data above, the harmonic value are majorly happened on 11^{th} harmonic order. So, the passive filter that will be installed are focused on reducing harmonic on 11^{th} order.

First, the filter must be sized, and below are how to fill the value of each variable;

- Capacitor kvar, µF, are determined from filter sizing.
- Capacitor Rated kV, Max. kV, are determined based on electrical network system. This determined value can be have a greater value due to protect the system from overload.
- Inductor X_{L1} value, are determined from filter sizing.
- Inductor Q Factor, Max. I, are determined based on electrical network system. This determined value can be changed gradually due to get the best result after doing another simulation while a passive filter are connected to the system.

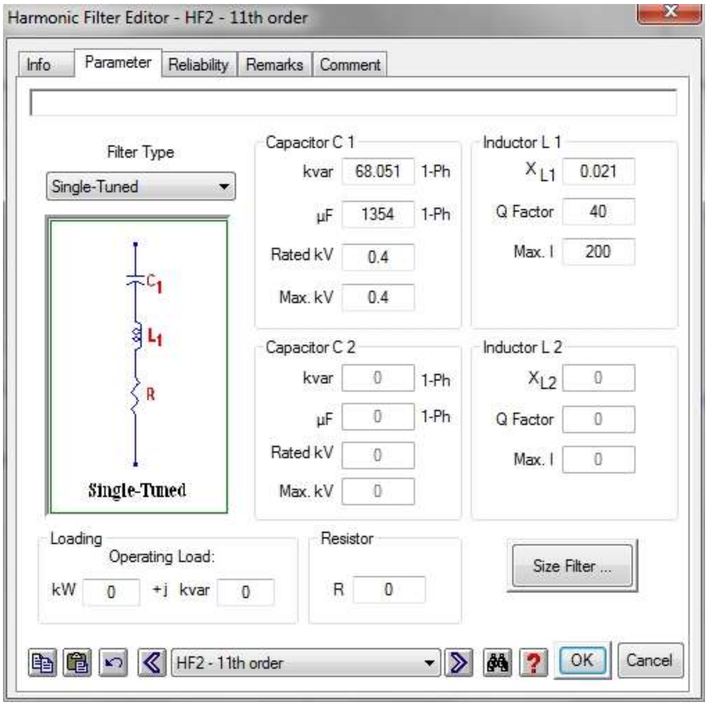

Figure 4. 31. Modelling Filter - Capacitor and Inductor

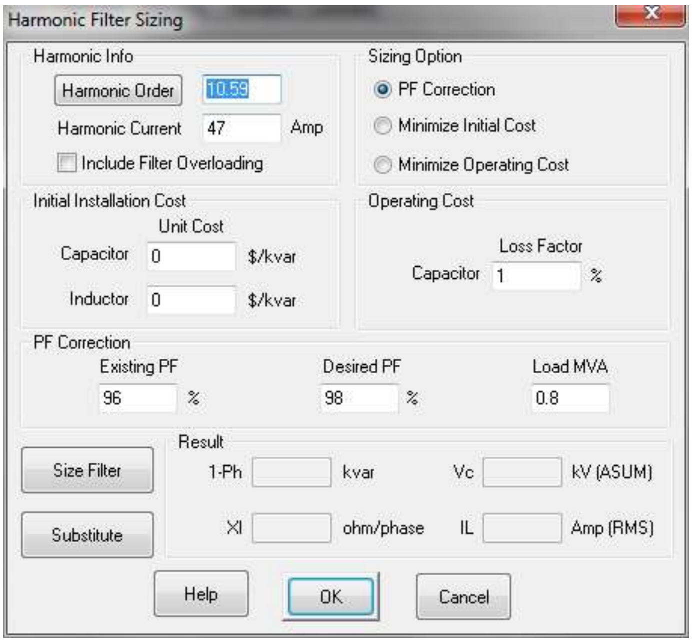

Figure 4. 32. Sizing Single-Tuned Passive Filter

To get the value of Capacitor kvar, μF, and Inductor X_{L1} value, it need to do a load flow simulation to get a PF value and a Load MVA value, while harmonic order and harmonic current are determined by doing a harmonic load flow analysis.

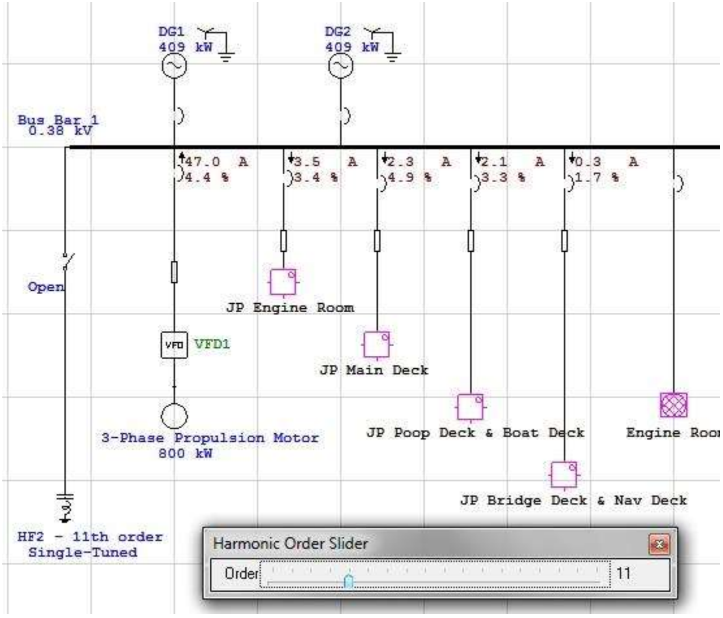

Figure 4. 33. Harmonic Load Flow Analysis

The result shows the cable that connecting Bus Bar 1 – VFD1 – 3-Phase Propulsion Motor are the highest value of harmonic current on the 11th order. This value then substituted to harmonic current and filter sizing. This value has a same amount on both condition (Sailing and Maneuvering).

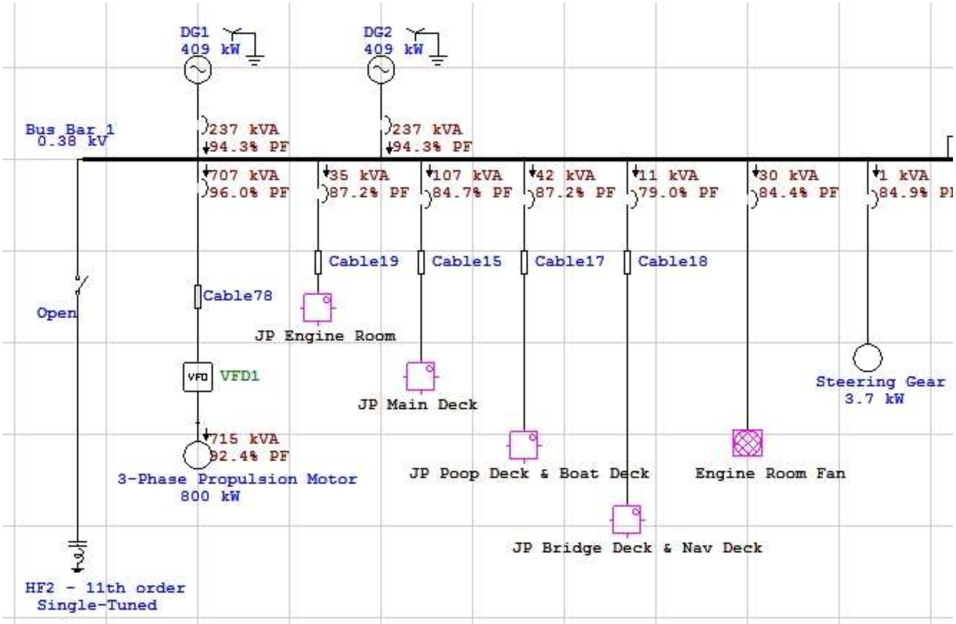

Figure 4. 34. Load Flow Analysis

Load flow analysis are needed to get the value of power factor (PF) for the same place or Cable78 (The cable that connecting Bus Bar 1 – VFD1 – 3-Phase Propulsion Motor). This value will be substituted to harmonic filter sizing to get a correction so the filter will increase the PF value.

4.6 Harmonic Simulation & Result

After modelling filter, the ship electrical network system is already fitted with a passive filter that will reduce the harmonic and distortion. This result will be compared to simulation without installing a passive filter. This is the important point of this thesis, evaluation from the result of installing and simulate passive filter on the ship electrical network system must be can reduce the harmonic and distortion on the system, and harmonic value shall not exceed 5% [6] complying with rules and standards.

Below are VTHD report of simulation with passive filter installed;

- **Sailing Condition**

Table 4. 8. Harmonic Load Flow Analysis Report – Sailing Condition, With Passive Filter

VTHD (Total Harmonic Distortion) Report - Passive Filter			
Bus		**Voltage Distortion**	
ID	kV	**Fund.** %	**VTHD** %
Cable78~	0.380	99.23	2.72
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

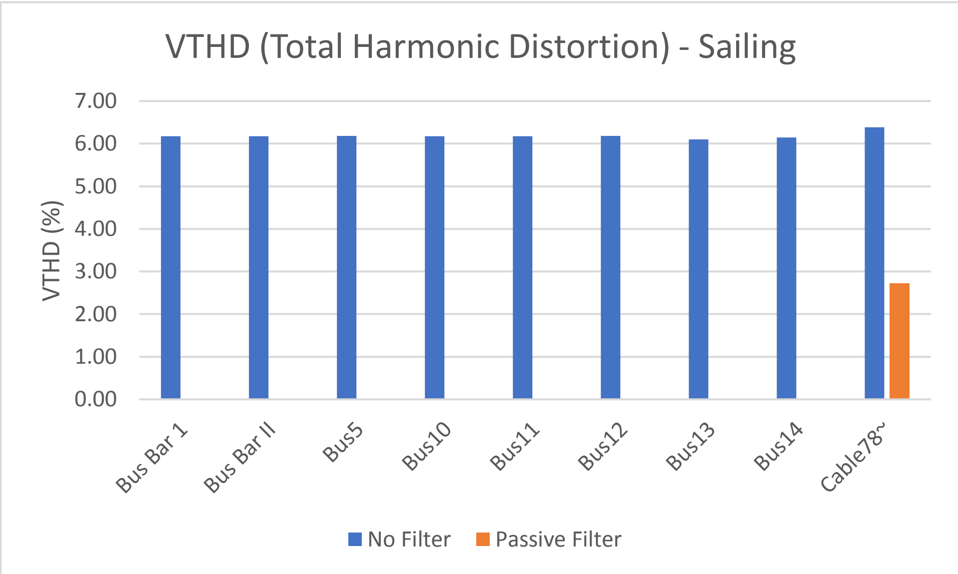

Figure 4. 35. VTHD value comparison - Sailing Condition

[6] DNV GL SE. *Electrical Installations (I-1-3)*. 2014.

- **Maneuvering Condition**

Table 4. 9. Harmonic Load Flow Analysis Report – Maneuvering Condition, With Passive Filter

VTHD (Total Harmonic Distortion) Report - Passive Filter			
Bus		Voltage Distortion	
ID	kV	Fund. %	VTHD %
Cable78~	0.380	99.23	2.72
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

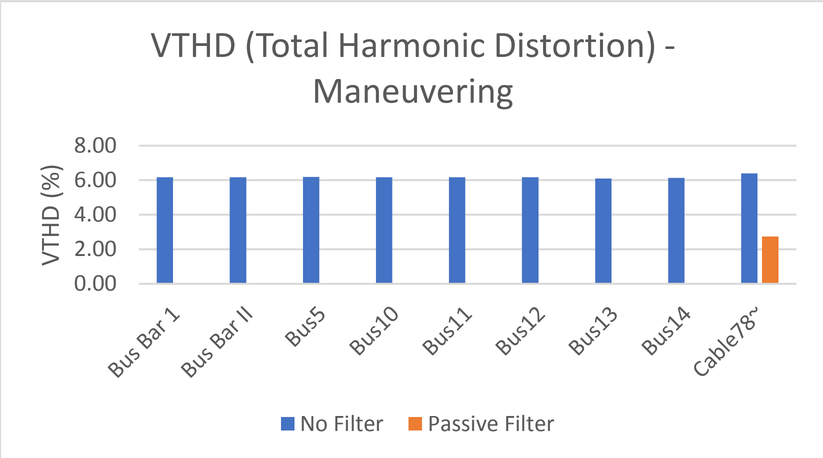

Figure 4. 36. VTHD value comparison - Maneuvering Condition

Both from sailing and maneuvering condition the VTHD value are reduced and mostly the VTHD value are disappear. But only Cable78 that has still VTHD value.

And below are the graphs that comparing between no filter situation and with passive filter situation;

- **Sailing Condition**

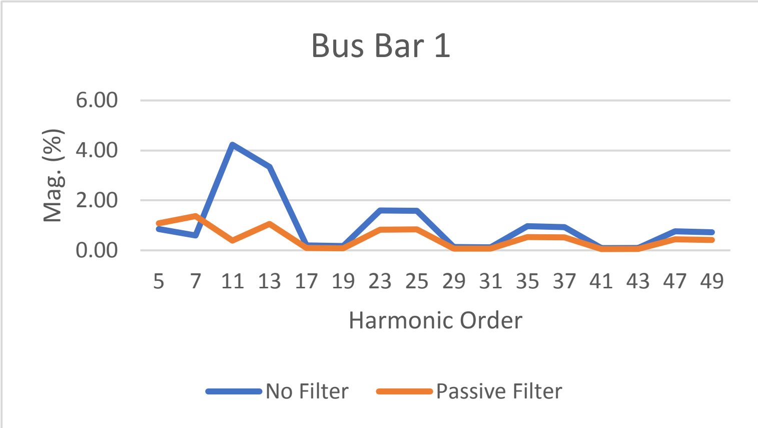

Figure 4. 37. Bus Bar 1 Harmonic value comparison - Sailing Condition

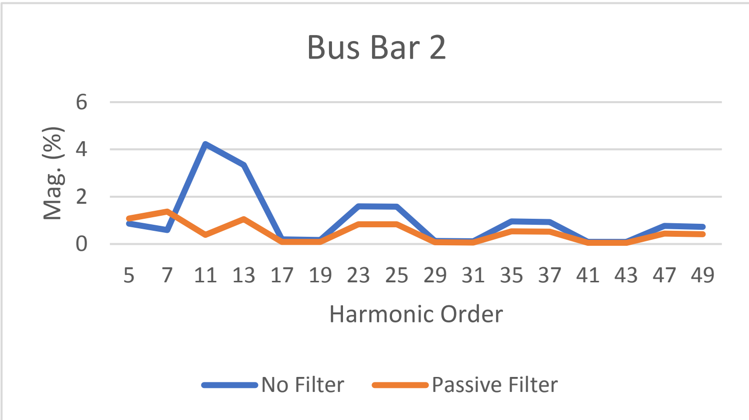

Figure 4. 38. Bus Bar 2 Harmonic value comparison - Sailing Condition

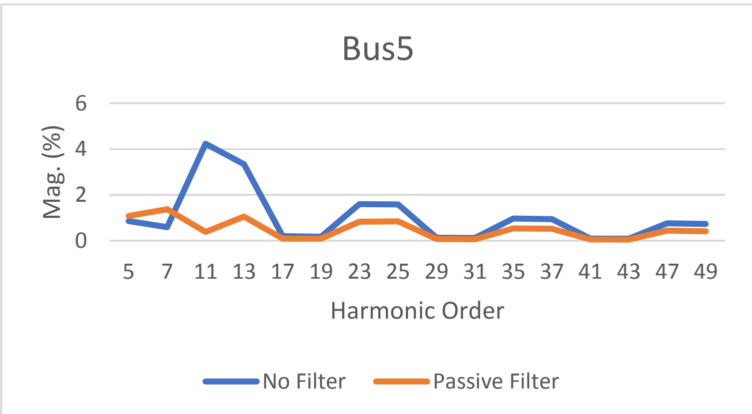

Figure 4. 39. Bus5 Harmonic value comparison - Sailing Condition

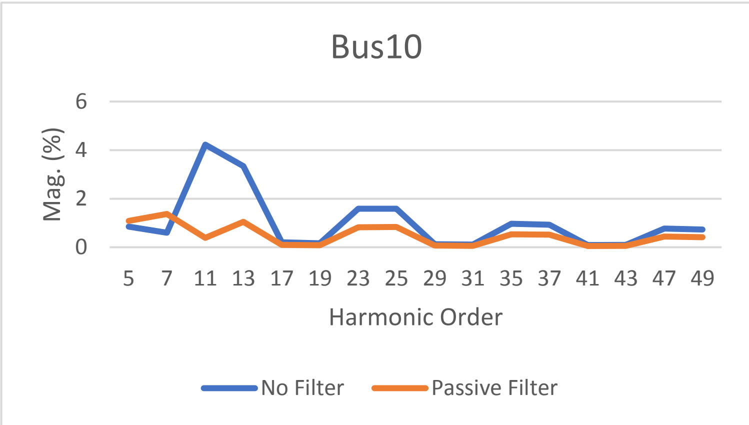

Figure 4. 40. Bus10 Harmonic value comparison - Sailing Condition

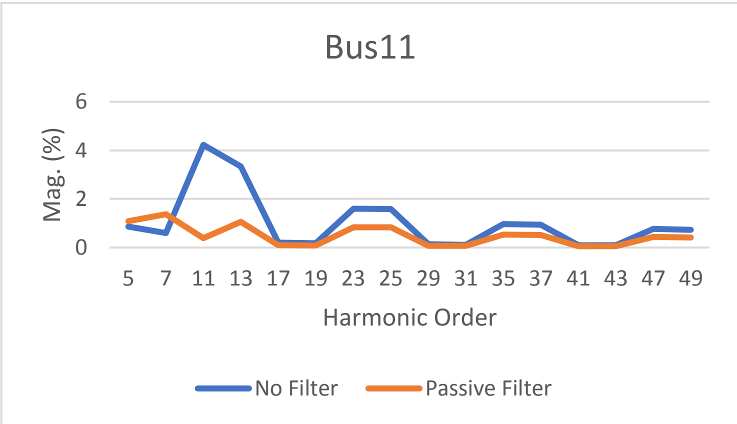

Figure 4. 41. Bus11 Harmonic value comparison - Sailing Condition

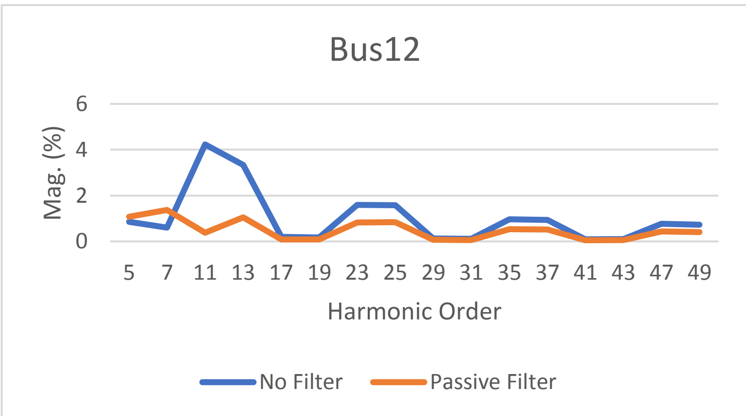

Figure 4. 42. Bus12 Harmonic value comparison - Sailing Condition

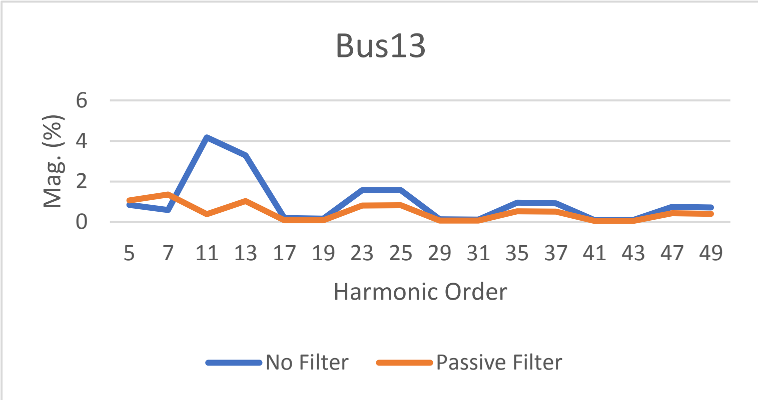

Figure 4. 43. Bus13 Harmonic value comparison - Sailing Condition

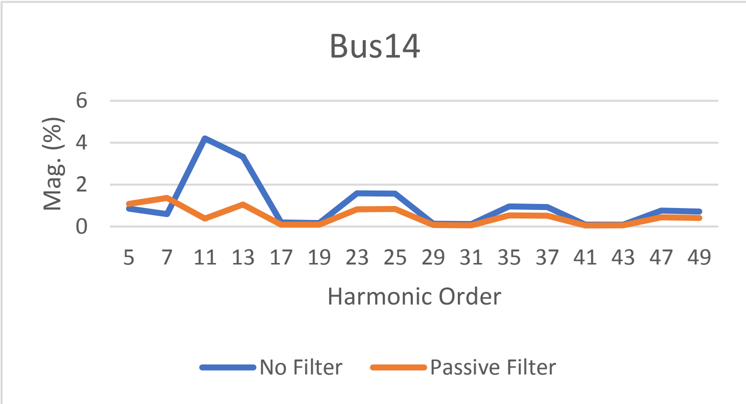

Figure 4. 44. Bus14 Harmonic value comparison - Sailing Condition

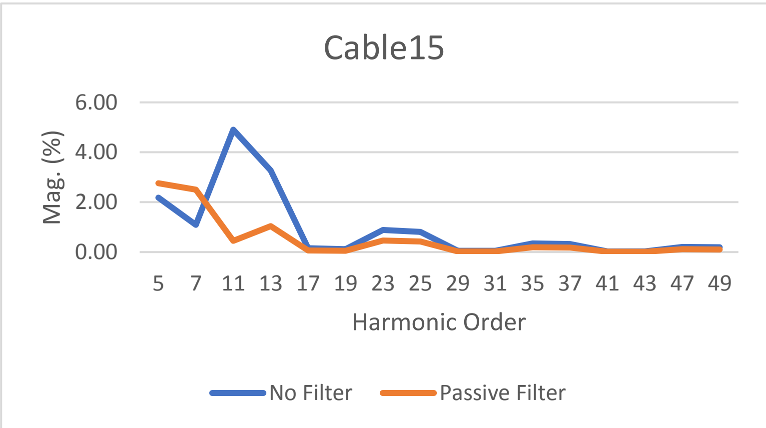

Figure 4. 45. Cable15 Harmonic value comparison - Sailing Condition

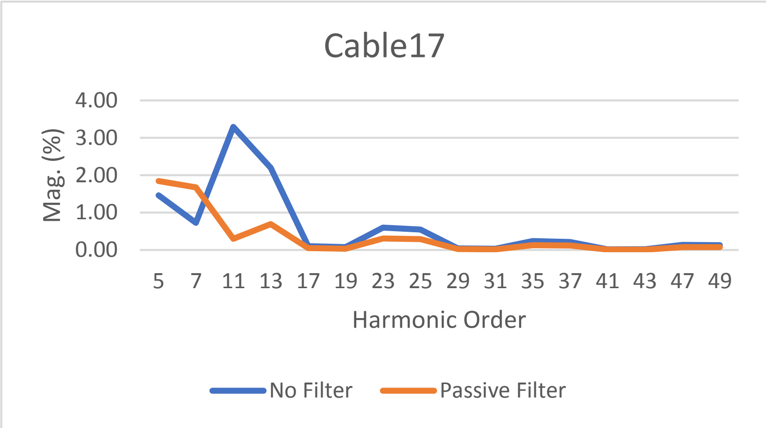

Figure 4. 46. Cable17 Harmonic value comparison - Sailing Condition

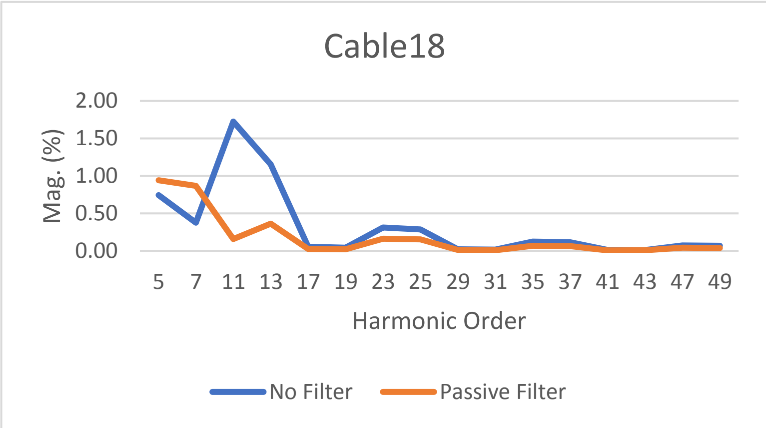

Figure 4. 47. Cable18 Harmonic value comparison - Sailing Condition

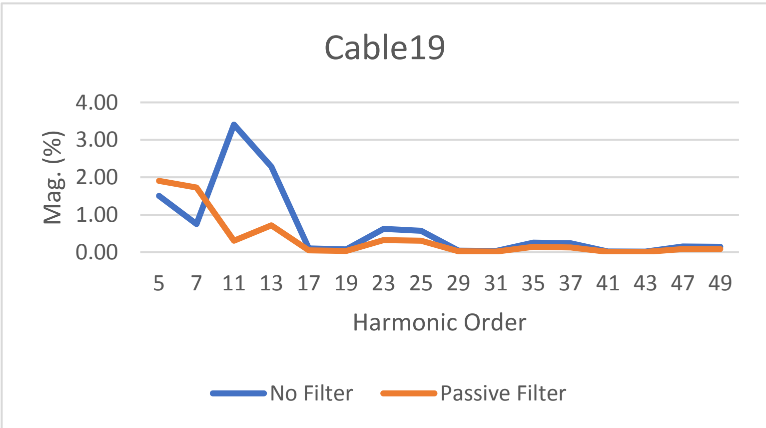

Figure 4. 48. Cable19 Harmonic value comparison - Sailing Condition

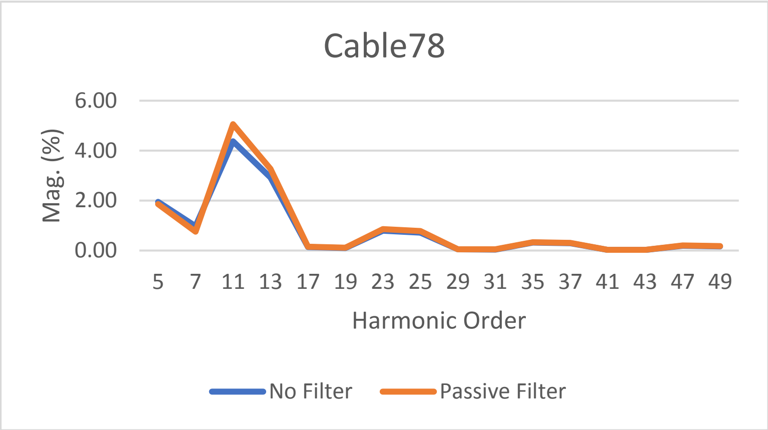

Figure 4. 49. Cable78 Harmonic value comparison - Sailing Condition

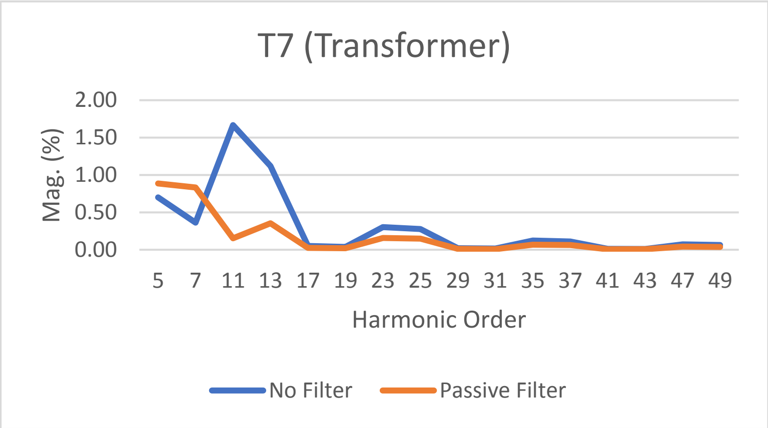

Figure 4. 50. T7 Harmonic value comparison - Sailing Condition

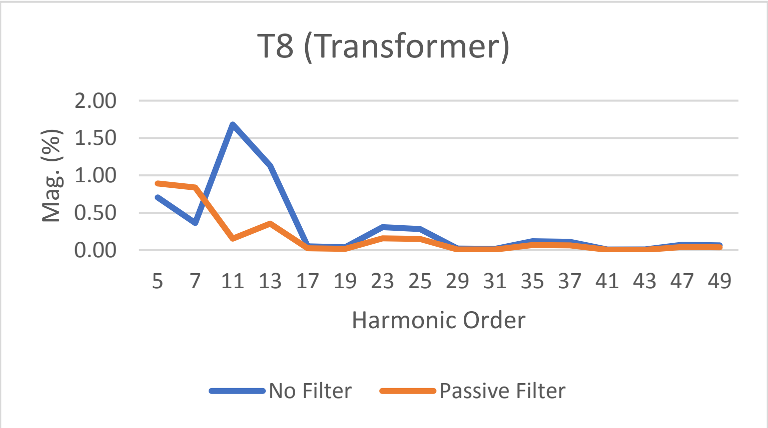

Figure 4. 51. T8 Harmonic value comparison - Sailing Condition

- **Maneuvering Condition**

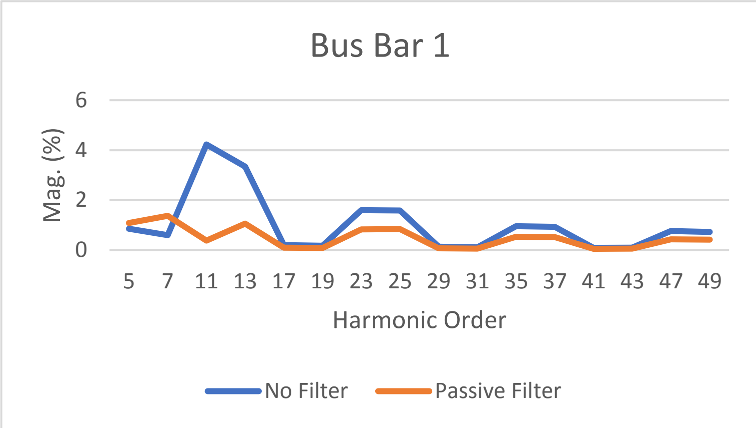

Figure 4. 52. Bus Bar 1 Harmonic value comparison - Maneuvering Condition

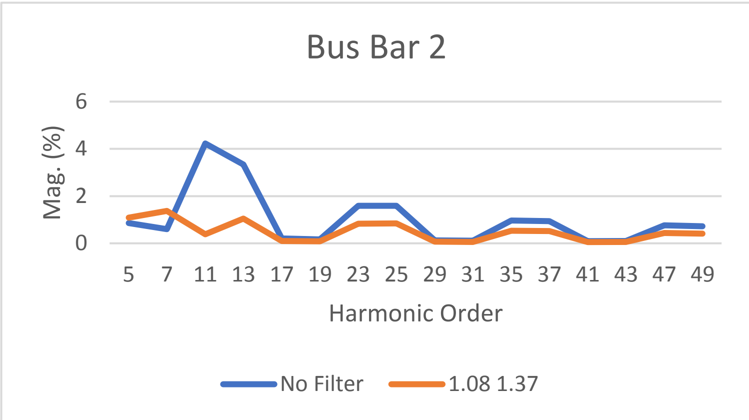

Figure 4. 53. Bus Bar 2 Harmonic value comparison - Maneuvering Condition

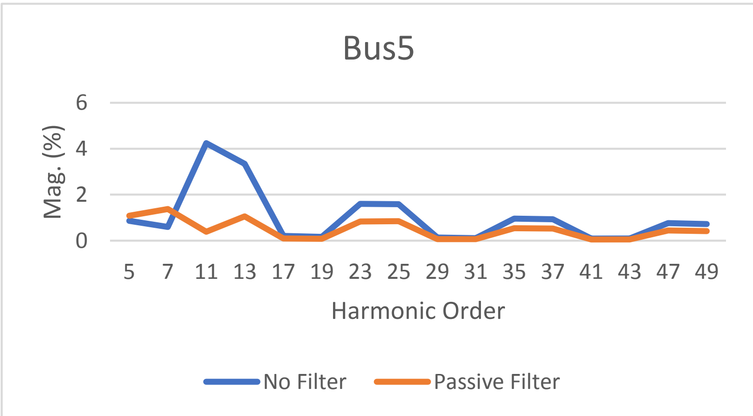

Figure 4. 54. Bus5 Harmonic value comparison - Maneuvering Condition

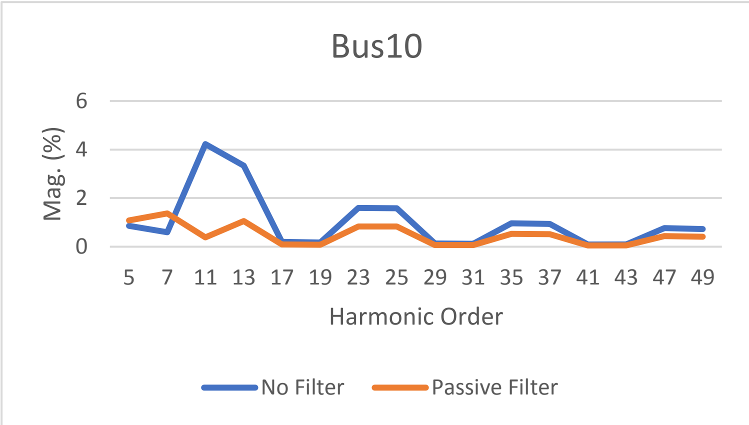

Figure 4. 55. Bus10 Harmonic value comparison - Maneuvering Condition

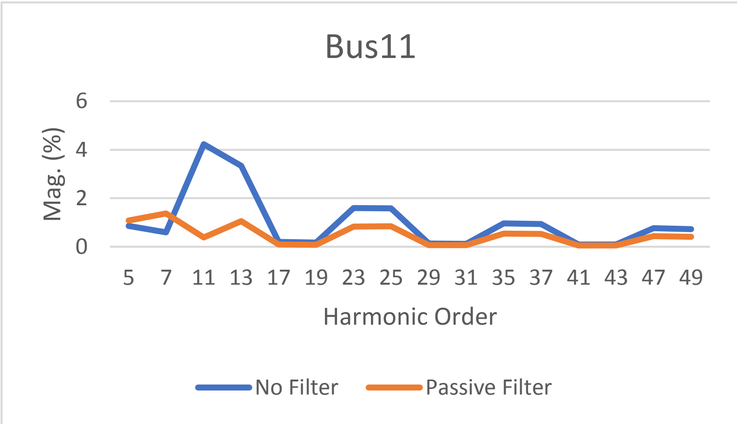

Figure 4. 56. Bus11 Harmonic value comparison - Maneuvering Condition

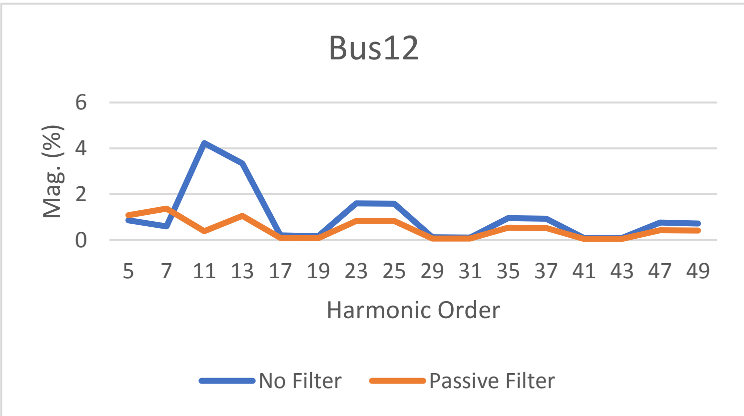

Figure 4. 57. Bus12 Harmonic value comparison - Maneuvering Condition

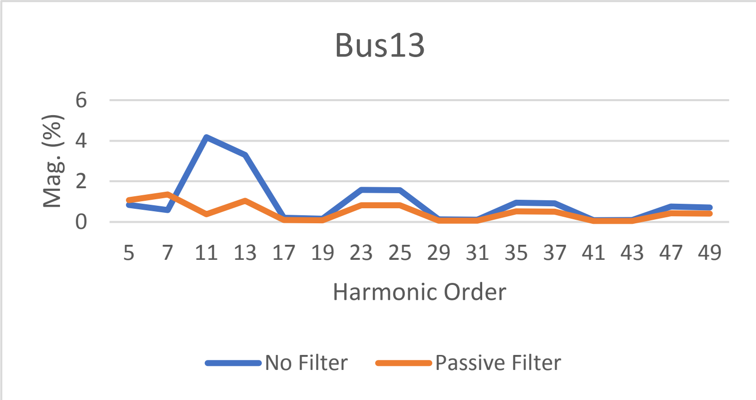

Figure 4. 58. Bus13 Harmonic value comparison - Maneuvering Condition

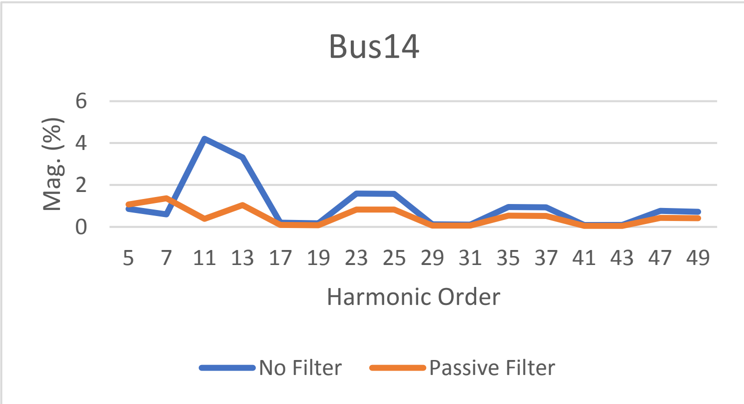

Figure 4. 59. Bus14 Harmonic value comparison - Maneuvering Condition

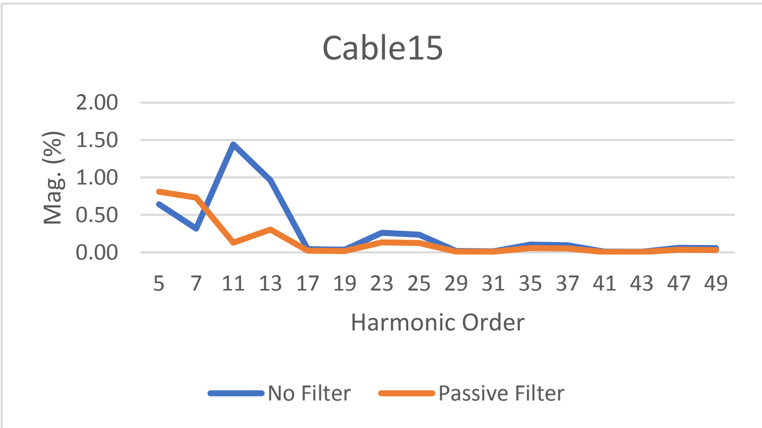

Figure 4. 60. Cable15 Harmonic value comparison - Maneuvering Condition

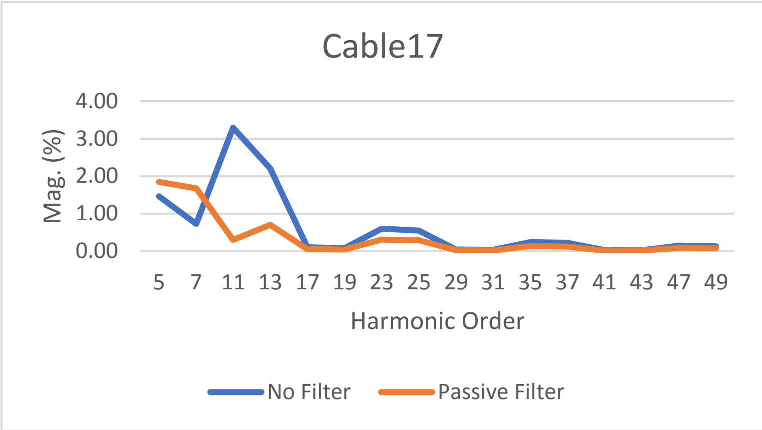

Figure 4. 61. Cable17 Harmonic value comparison - Maneuvering Condition

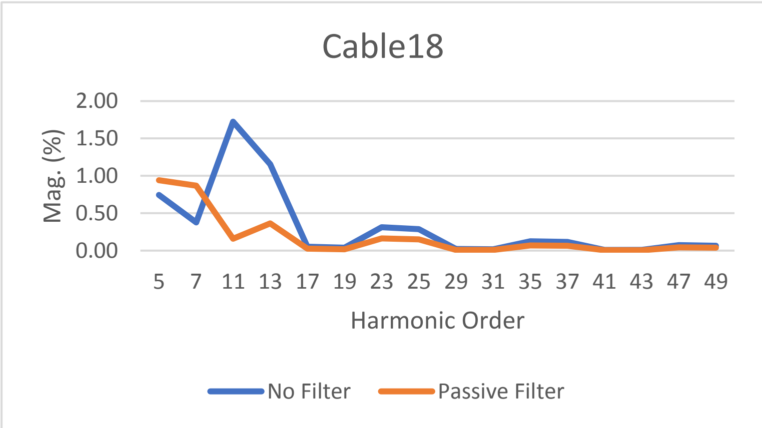

Figure 4. 62. Cable18 Harmonic value comparison - Maneuvering Condition

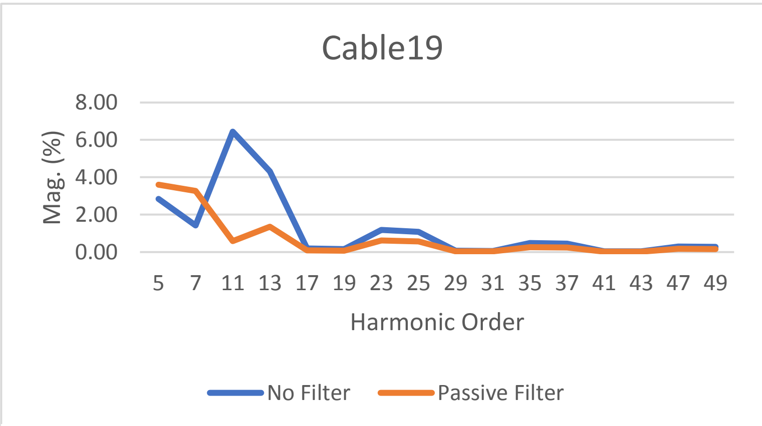

Figure 4. 63. Cable19 Harmonic value comparison - Maneuvering Condition

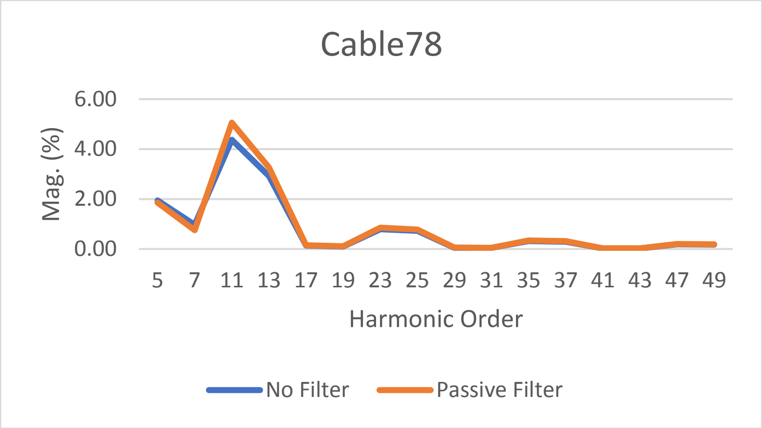

Figure 4. 64. Cable78 Harmonic value comparison - Maneuvering Condition

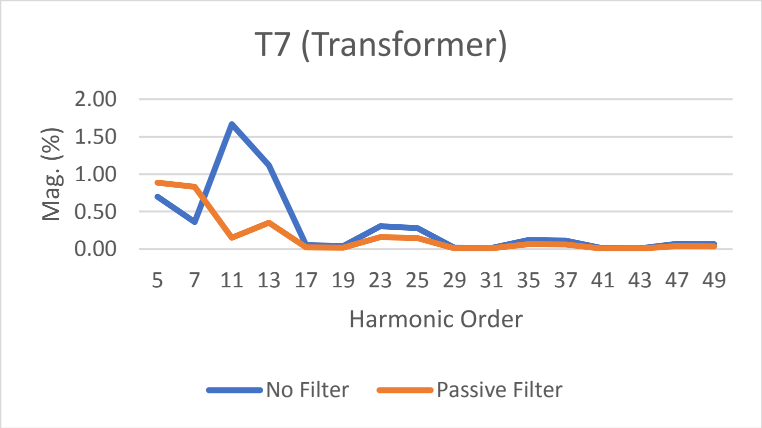

Figure 4. 65. T7 Harmonic value comparison - Maneuvering Condition

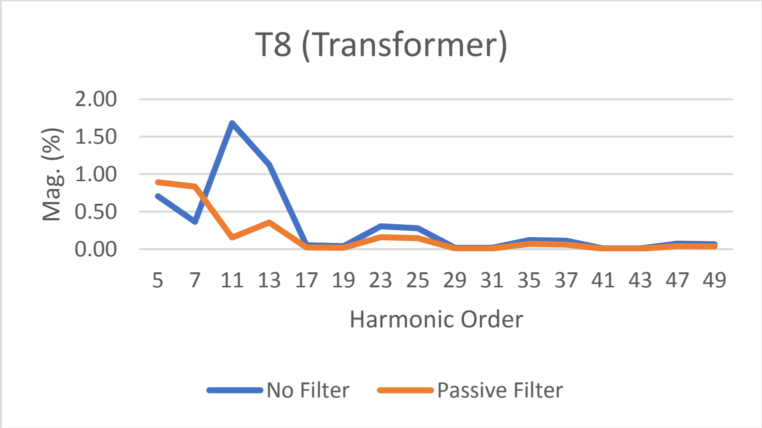

Figure 4. 66. T8 Harmonic value comparison - Maneuvering Condition

From both condition, the Mag. value are almost having same value. Both condition also have a similarity that 11th order is reduced on all device except for Cable78 that even with installing passive filter the Mag. value are gained a little more value. Although if all the Mag. value summed up, the VTHD of all device are reduced.

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CHAPTER 5
CONCLUSION

5.1 Conclusion

Based on the data analysis and simulation, conclusion of this thesis are as follows;

1. Below are the result from software of harmonic load flow analysis report without using a harmonic filter;

Table 5. 1. VTHD Report - Sailing - No Harmonic Filter

VTHD (Total Harmonic Distortion) Report - No Filter			
Bus		Voltage Distortion	
ID	kV	Fund. %	VTHD %
Bus Bar 1	0.380	100.00	6.18
Bus Bar II	0.380	100.00	6.18
Bus5	0.380	99.86	6.18
Bus10	0.380	99.97	6.18
Bus11	0.380	99.99	6.18
Bus12	0.380	99.93	6.18
Bus13	0.220	99.71	6.10
Bus14	0.220	99.77	6.14
Cable78~	0.380	99.23	6.39
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

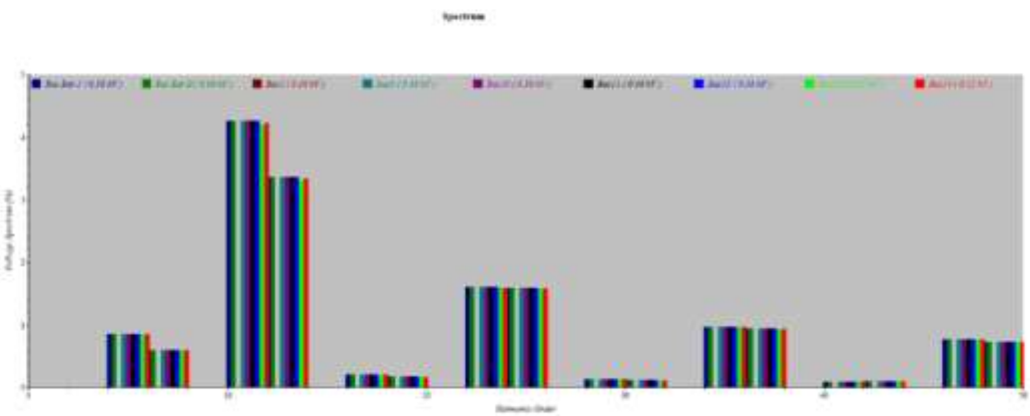

Figure 5. 1. Harmonic Spectrum Report – Sailing Condition, No Harmonic Filter

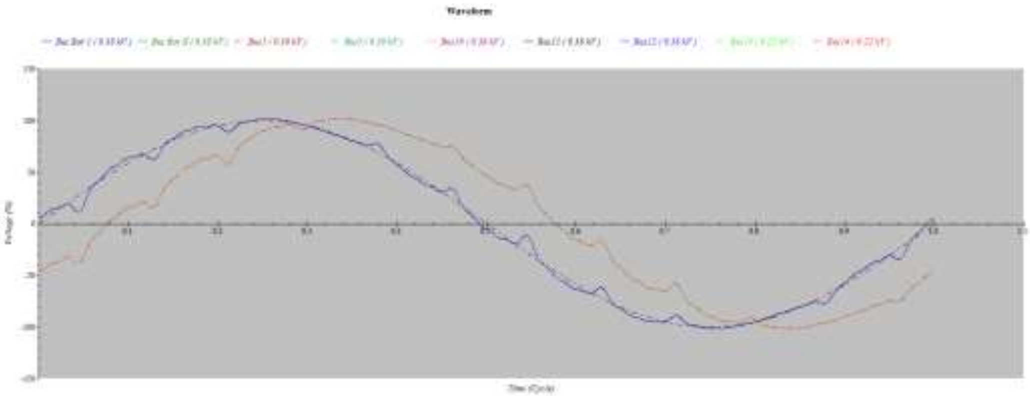

Figure 5. 2. Harmonic Waveform Report – Sailing Condition, No Harmonic Filter

Table 5. 2. VTHD Report – Maneuvering – No Filter

VTHD (Total Harmonic Distortion) Report - No Filter			
Bus		Voltage Distortion	
ID	kV	Fund. %	VTHD %
Bus Bar 1	0.380	100.00	6.18
Bus Bar II	0.380	100.00	6.18
Bus5	0.380	99.54	6.20
Bus10	0.380	99.98	6.17
Bus11	0.380	99.99	6.18
Bus12	0.380	99.93	6.18
Bus13	0.220	99.71	6.10
Bus14	0.220	99.77	6.14
Cable78~	0.380	99.23	6.39
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

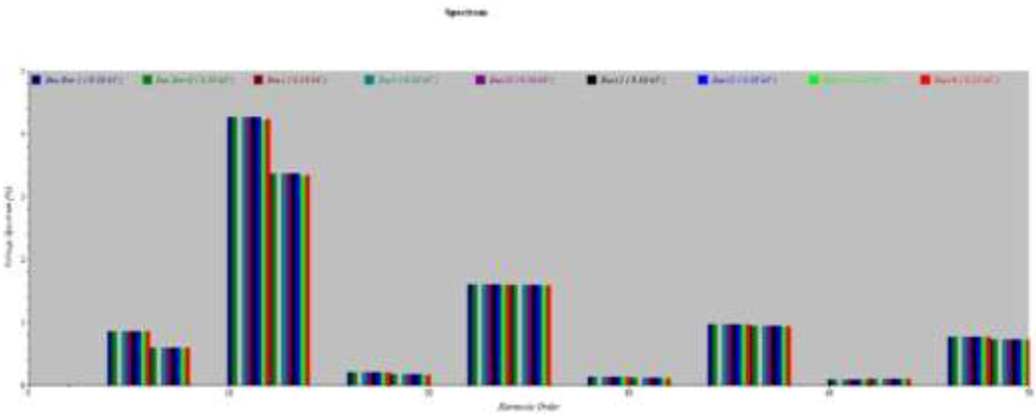

Figure 5. 3. Harmonic Spectrum Report – Maneuvering Condition, No Harmonic Filter

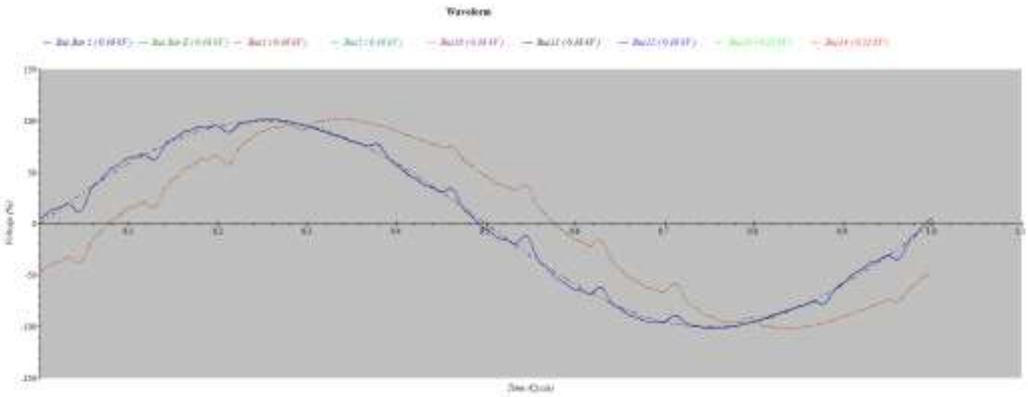

Figure 5. 4. Harmonic Waveform Report – Maneuvering Condition, No Harmonic Filter

From the data above, VTHD value are not comply with the DNV GL Rules that the total voltage harmonic distortion shall not exceed 5%.

2. Designing a proper single-tuned passive harmonic filter are based on the harmonic value that are mostly highest value of harmonic order. From the result of harmonic load flow analysis, the passive filter that will be installed are focused on reducing harmonic on 11th order. Single-tuned passive harmonic filter consists of inductor and capacitor as shown in Figure 5. 5.

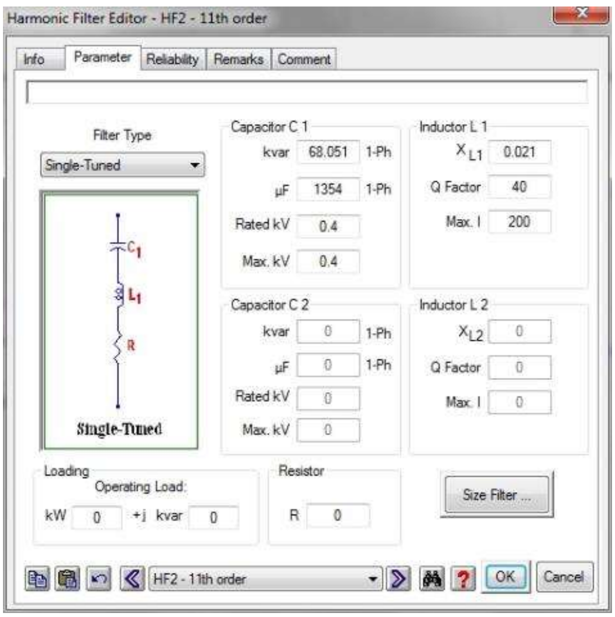

Figure 5. 5. Designing Single-Tuned Passive Harmonic Filter

Figure. 5. 5. are represent how to design a proper passive harmonic filter with a single-tuned type. Capacitor and inductor value are determined by size filter option that capacitor kvar, μF, are determined from filter sizing. Capacitor Rated kV, Max. kV, are determined based on electrical network system. This determined value can be have a greater value due to protect the system from overload. Inductor XL1 value, are determined from filter sizing. Inductor Q Factor, Max. I, are determined based on electrical network system. This determined value can be changed gradually due to get the best result after doing another simulation while a passive filter are connected to the system.
Passive harmonic filter can reduce the VTHD value by reducing a specific harmonic order and the impact from reducing specific harmonic order can reduce the other harmonic order.

3. Below are the result from software of harmonic load flow analysis report using a passive harmonic filter;

Table 5. 3. VTHD Report - Sailing - With Passive Harmonic Filter

VTHD (Total Harmonic Distortion) Report - Passive Filter			
Bus		Voltage Distortion	
ID	kV	Fund.	VTHD
		%	%
Cable78~	0.380	99.23	2.72
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

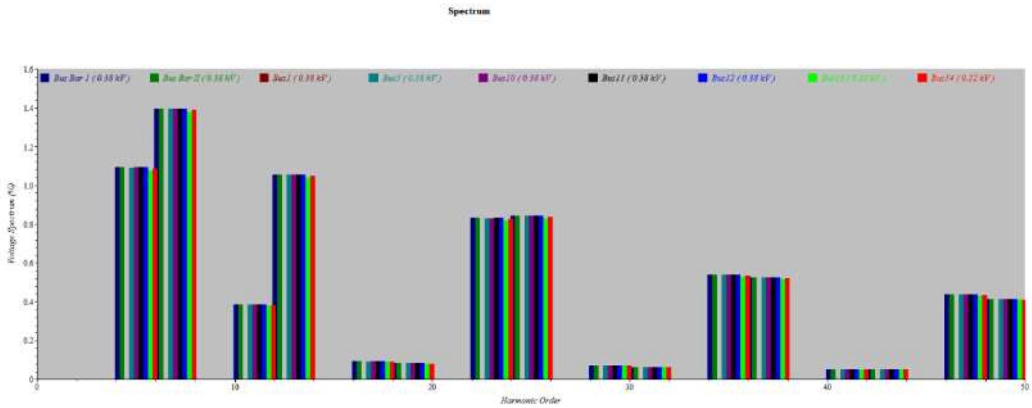

Figure 5. 7. Harmonic Spectrum Report – Sailing Condition, with Passive Harmonic Filter

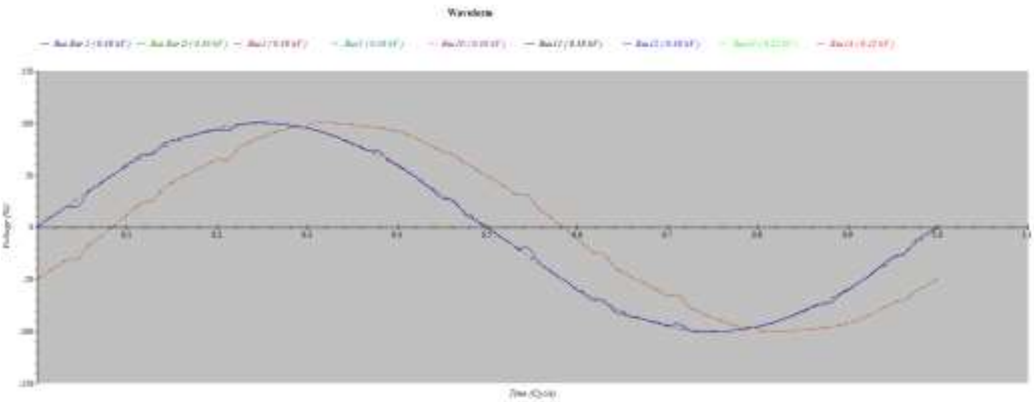

Figure 5. 6. Harmonic Waveform Report – Sailing Condition, with Passive Harmonic Filter

Table 5. 4. VTHD Report - Maneuvering - With Passive Harmonic Filter

VTHD (Total Harmonic Distortion) Report - Passive Filter			
Bus		**Voltage Distortion**	
ID	kV	**Fund.** %	**VTHD** %
Cable78~	0.380	99.23	2.72
Indicates buses with THD (Total Harmonic Distortion) exceeding the limit			

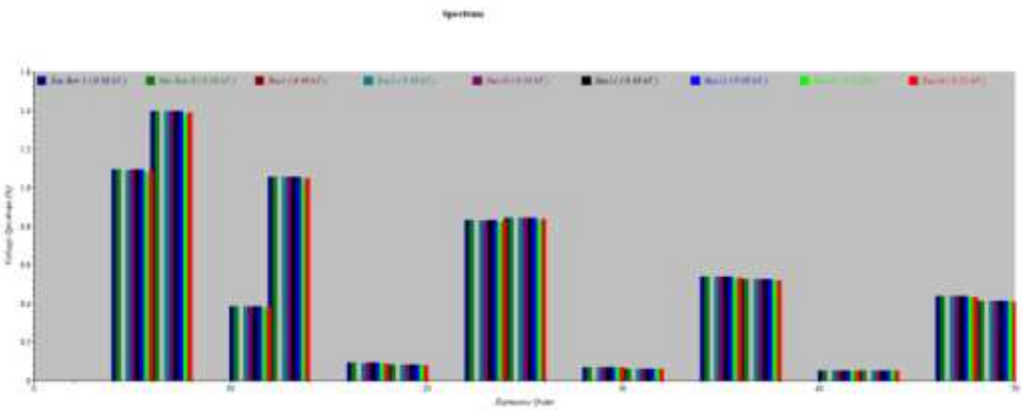

Figure 5. 8. Harmonic Spectrum Report – Maneuvering Condition, with Passive Harmonic Filter

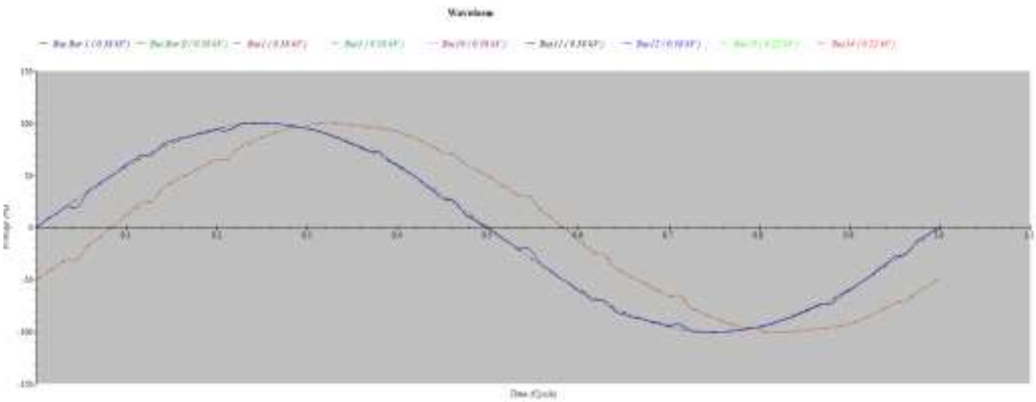

Figure 5. 9. Harmonic Waveform Report – Maneuvering Condition, with Passive Harmonic Filter

From the data above VTHD value are comply with the DNV GL Rules that the total voltage harmonic distortion shall not exceed 5%.

5.2 Recommendation

There are also some recommendation from this thesis are as follows;

1. There is further research to calculate the economic value to compare between no filter and with passive filter condition.
2. There is further research with the data taken from any ship with an electrical propulsion system.
3. There is further research to reduce total harmonic distortion value with another type of harmonic filter.

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[9] Young-Sik Cho & Hanju Cha (2011), *Single-tuned Passive Harmonic Filter Design Considering Variances of Tuning and Quality Factor*, Journal of International Council on Electrical Engineering, 1:1, 7-13, DOI: 10.5370/JICEE.2011.1.1.007

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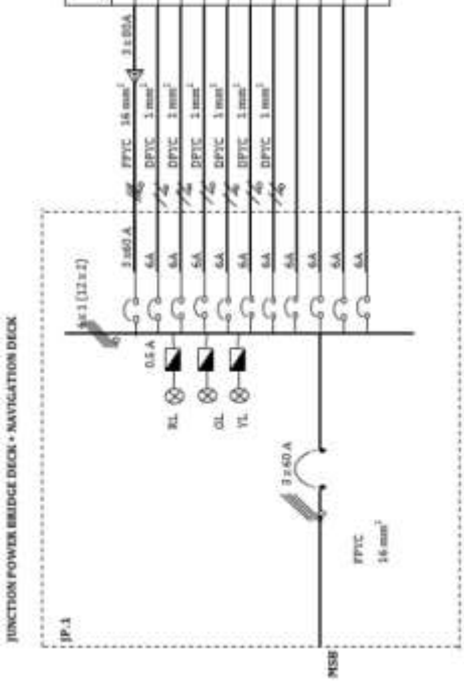
ATTACHMENT

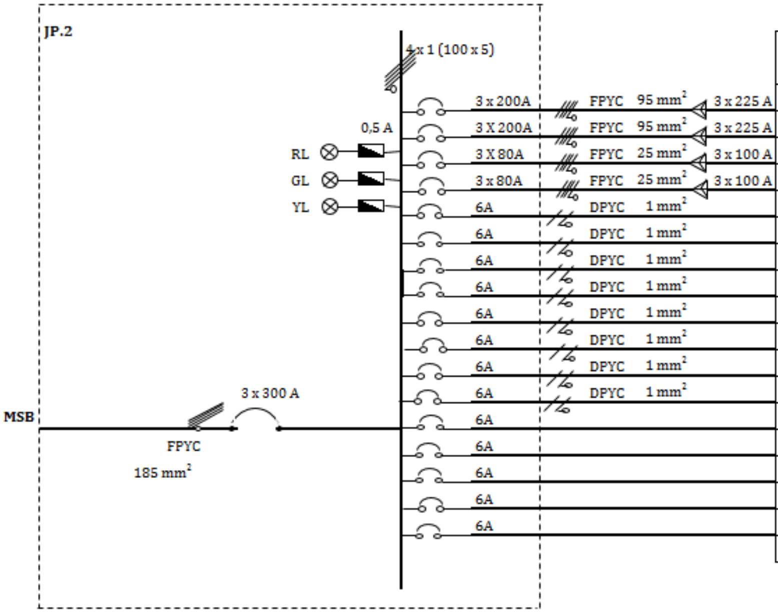
- **Junction Power 1 (Bridge Deck + Navigation Deck)**

No. Saluran	I Nom. (A)	I Start (A)	Peralatan		Power (kW)	Input (kW)	Daya (kW)		
							R	S	T
1	11.995	35.904	Provision Crane	(380V, 3φ, 50Hz)	6	6.316	2.105	2.105	2.105
2	0.598	1.794	Accomodation Supply Fan 1	(220V, 1φ, 50Hz)	0.3	0.316	0.316		
3	0.598	1.794	Accomodation Supply Fan 2	(220V, 1φ, 50Hz)	0.3	0.316		0.316	
4	0.598	1.794	Accomodation Supply Fan 3	(220V, 1φ, 50Hz)	0.3	0.316			0.316
5	0.598	1.794	Accomodation Exhaust Fan 1	(220V, 1φ, 50Hz)	0.3	0.316	0.316		
6	0.598	1.794	Accomodation Exhaust Fan 2	(220V, 1φ, 50Hz)	0.3	0.316		0.316	
7	0.598	1.794	Accomodation Exhaust Fan 3	(220V, 1φ, 50Hz)	0.3	0.316			0.316
11									
12									
13									
14									
TOTAL POWER					7.8	8.211	2.737	2.737	2.737



- **Junction Power 2 (Poop Deck + Boat Deck)**

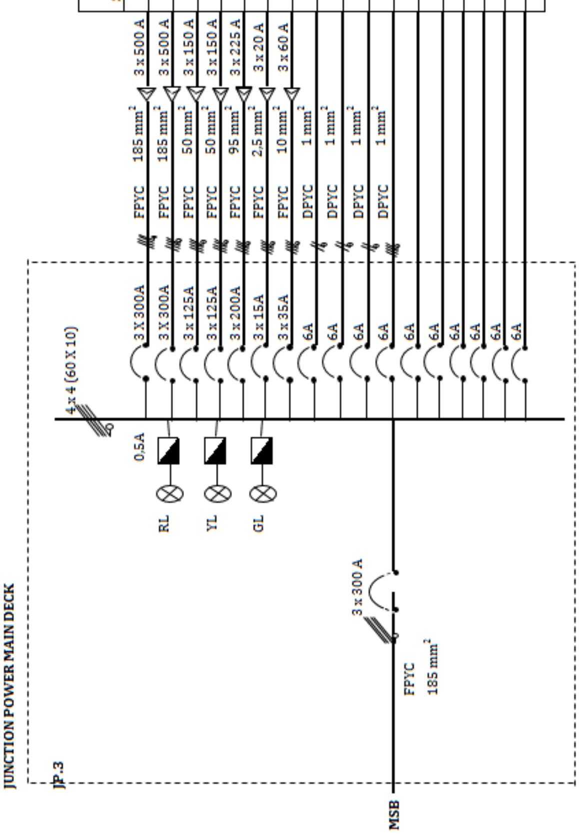
JUNCTION POWER POOP DECK + BOAT DECK



No. Saluran	I Nom. (A)	I Start (A)	Peralatan		Power (kW)	Input (kW)	Daya (kW)		
							R	S	T
1	51,978	155,933	Windllas	(380V, 3φ, 50Hz)	26	27,368	9,123	9,123	9,123
2	51,978	155,933	Windllas	(380V, 3φ, 50Hz)	26	27,368	9,123	9,123	9,123
3	23,990	71,969	Capstan	(380V, 3φ, 50Hz)	12	12,632	4,211	4,211	4,211
4	23,990	71,969	Capstan	(380V, 3φ, 50Hz)	12	12,632	4,211	4,211	4,211
5	1,794		Accomodation Supply Fan 1	(220V, 1φ, 50Hz)	0,3	0,316	0,316		
6	1,794		Accomodation Supply Fan 2	(220V, 1φ, 50Hz)	0,3	0,316		0,316	
7	1,794		Accomodation Supply Fan 1	(220V, 1φ, 50Hz)	0,3	0,316			0,316
8	1,794		Accomodation Supply Fan 2	(220V, 1φ, 50Hz)	0,3	0,316		0,316	
9	1,794		Accomodation Exhaust Fan 1	(220V, 1φ, 50Hz)	0,3	0,316	0,316		
10	1,794		Accomodation Exhaust Fan 2	(220V, 1φ, 50Hz)	0,3	0,316		0,316	
11	1,794		Accomodation Exhaust Fan 1	(220V, 1φ, 50Hz)	0,3	0,316	0,316		
12	1,794		Accomodation Exhaust Fan 2	(220V, 1φ, 50Hz)	0,3	0,316			0,316
13			SPARE						
14									
15									
16									
17									
TOTAL POWER					78,4	82,526	27,61	27,61	27,3

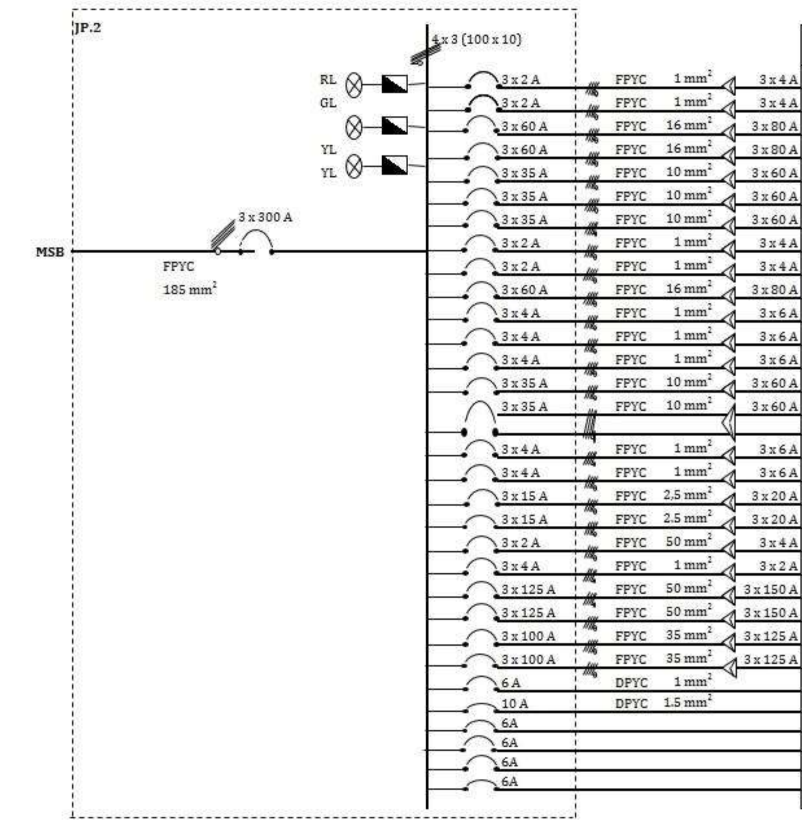
- **Junction Power 3 (Main Deck)**

No. Saluran	I Nom. (A)	I Start (A)	Peralatan		Power (kW)	Input (kW)	Daya (kW)		
							R	S	T
1	49,978	149,935	Cargo Pump	(380V, 3φ, 50Hz)	25	26,316	8,772	8,772	8,772
2	49,978	149,935	Cargo Pump	(380V, 3φ, 50Hz)	25	26,316	8,772	8,772	8,772
3	1,499	4,498	Stripping Pump	(380V, 3φ, 50Hz)	0,75	0,789		0,789	
4	1,499	4,498	Stripping Pump	(380V, 3φ, 50Hz)	0,75	0,789			0,789
5	59,974	179,922	Cargo Crane	(380V, 3φ, 50Hz)	30	31,579	10,53	10,53	10,53
6	0,000	0,000							
7	0,000	0,000							
8	1,794		Accomodation Supply Fan 1	(220V, 1φ, 50Hz)	0,3	0,316	0,316		
9	1,794		Accomodation Supply Fan 2	(220V, 1φ, 50Hz)	0,3	0,316		0,316	
10	1,794		Accomodation Exhaust Fan 1	(220V, 1φ, 50Hz)	0,3	0,316			0,316
11	1,794		Accomodation Exhaust Fan 2	(220V, 1φ, 50Hz)	0,3	0,316	0,316		
12			SPARE				-	-	-
13									-
14								-	
15							-		
16								-	
17									-
TOTAL POWER					82,7	87,053	28,7	29,18	29,18



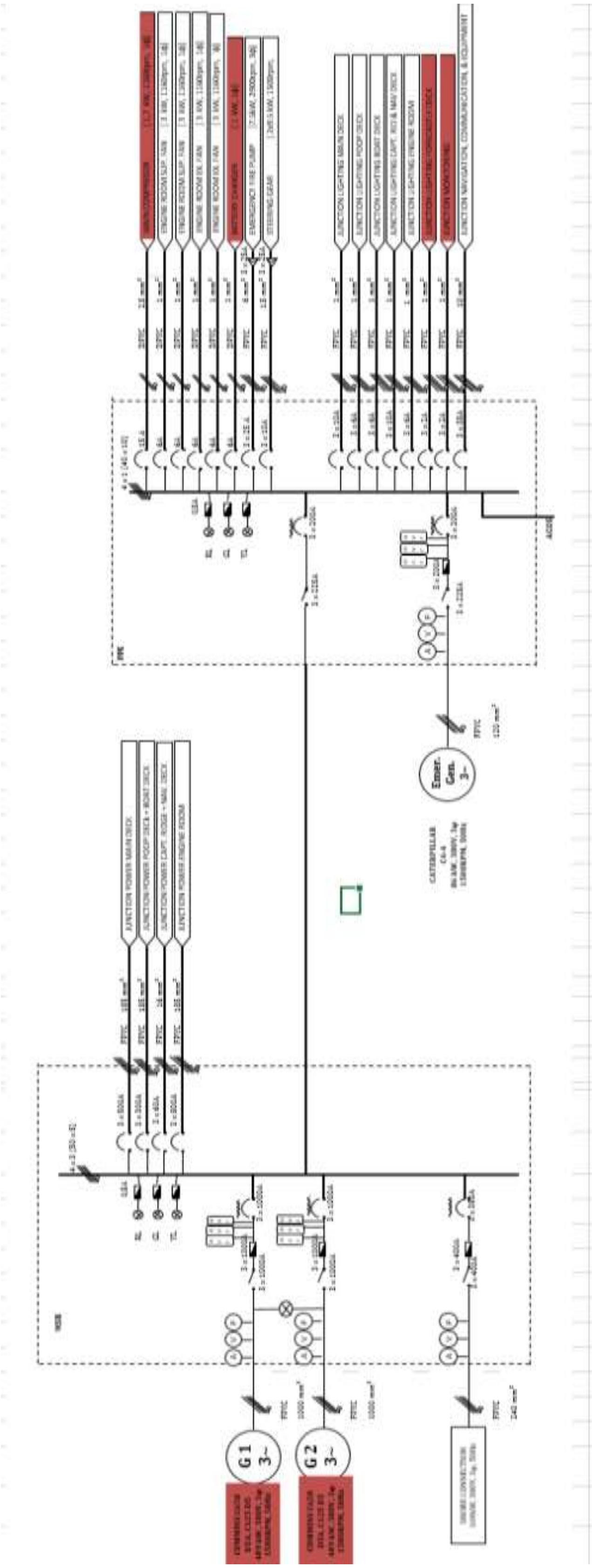
- **Junction Power 4 (Engine Room)**

JUNCTION POWER ENGINE ROOM

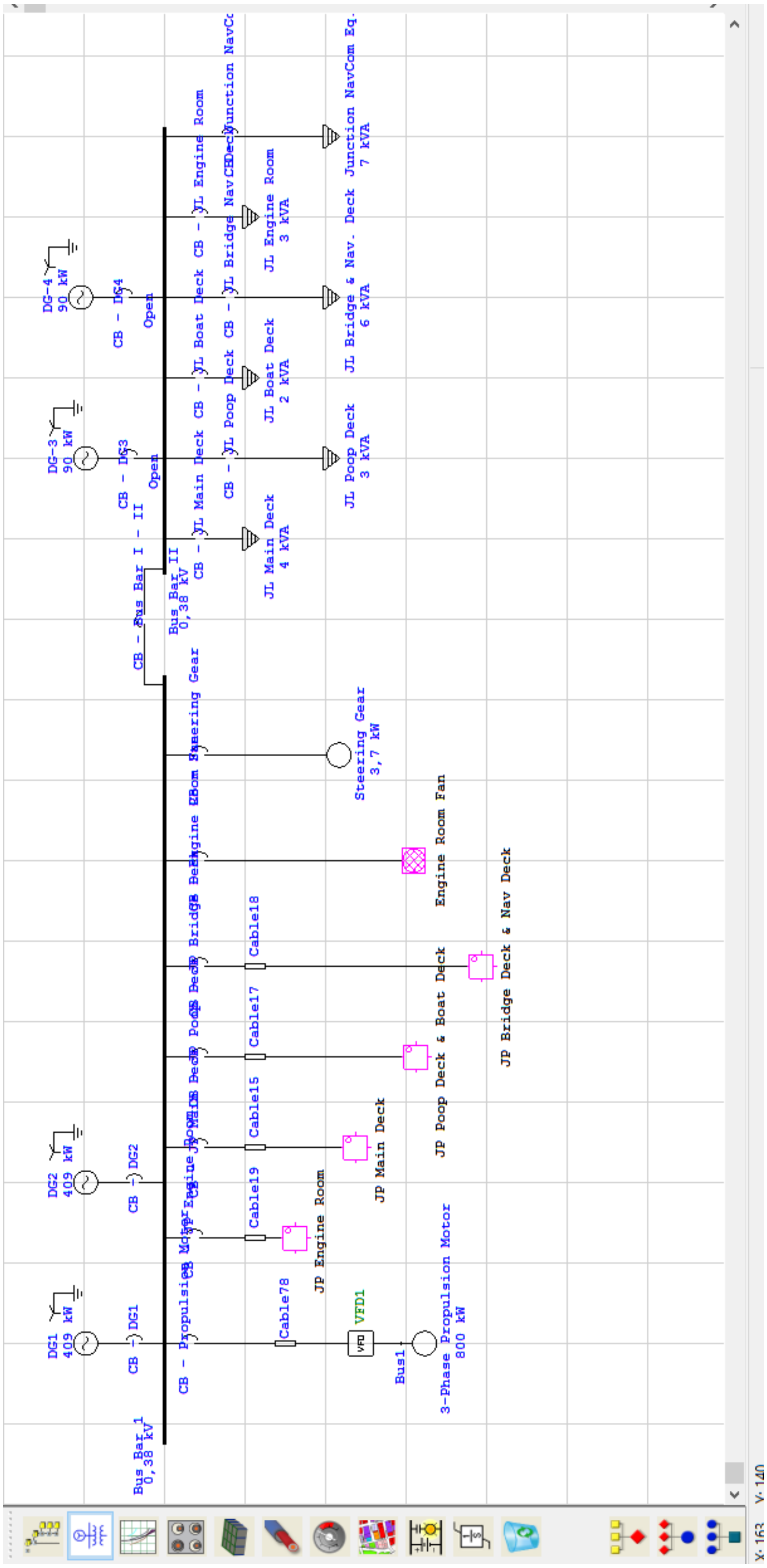


No. Saluran	I Nom. (A)	I Start (A)	Peralatan		Power (kW)	Input (kW)	Daya (kW)		
							R	S	T
1	0.000	0.000							
2	0.000	0.000							
3	0.000	0.000							
4	0.000	0.000							
5	0.000	0.000							
6	0.000	0.000							
7	0.000	0.000							
8	0.000	0.000							
9	0.000	0.000							
10	0.000	0.000							
11	13.158	39.474	SW Cooling Pump 1		2.20	2.316	2.316		
12	13.158	39.474	SW Cooling Pump 2		2.20	2.316		2.316	
13	2.999	8.996	Central Cooling	(380V, 3φ, 50Hz)	1.50	1.579	0.526	0.526	0.526
14	0.000	0.000							
15	0.000	0.000							
16	13.158	39.474	CO Transfer Pump		2.20	2.316		2.316	
17	0.000	0.000							
18	0.000	0.000							
19	0.000	0.000							
20	0.000	0.000							
21	16.148	48.445	Oily Water Separator	(380V, 3φ, 50Hz)	2.70	2.842			2.842
22	11.962	35.885	Oily Bilge Pump	(380V, 3φ, 50Hz)	6.00	6.316	2.105	2.105	2.105
23	36.984	110.952	Ballast Pump 1	(380V, 3φ, 50Hz)	18.50	19.474	6.491	6.491	6.491
24	36.984	110.952	Ballast Pump 2	(380V, 3φ, 50Hz)	18.50	19.474	6.491	6.491	6.491
25	21.990	65.971	Fire Pump 1	(380V, 3φ, 50Hz)	11.00	11.579	3.860	3.860	3.860
26	21.990	65.971	Fire Pump 2	(380V, 3φ, 50Hz)	11.00	11.579	3.860	3.860	3.860
27	0.000								
28	0.000								
29			SPARE				-		
30								-	
31									-
32							-	-	-
			Total Power		75.80	79.79	25.65	27.96	26.18

- **Main Switch Board (MSB)**



- **Main Switchboard on ETAP**



- **3-Phase Induction Motor and VFD Specification**

Technical data for Marine cast iron motors
Marine cast iron motors 1000 r/min, 380 V, 50 Hz

IP 55 - IC 411 - Insulation class F, temperature rise class F

Output kW	Motor type	Product code	Speed r/min	Efficiency IEC 60034-30-1; 2014 Full load 100%	3/4 load 75%	1/2 load 50%	Power factor Cosφ	Current I_N A	I_s/I_N	Torque T_N Nm	T_l/T_N	T_b/T_N	Moment of inertia J = 1/4 GD² kgm²	Weight kg	Sound pressure Level L_{pA} dB
1000 r/min = 6 poles				380 V 50 Hz				CENELEC-design							
160	M3BP 355SMA 6	3GBP353210-•DG	992	96,3	95,6	95,1	0,84	303	6,3	1540	1,8	2,3	7,9	1520	75
200	M3BP 355SMB 6	3GBP353220-•DG	992	95,6	95,8	95,5	0,84	379	6,4	1925	1,9	2,4	9,7	1680	75
250	M3BP 355SMC 6	3GBP353230-•DG	992	95,8	95,7	95,3	0,83	478	6,7	2406	2,3	2,6	11,3	1820	75
315	M3BP 355MLB 6	3GBP353420-•DG	991	95,8	95,9	95,5	0,86	580	6,3	3035	2,2	2,4	13,5	2180	75
355	M3BP 355LKA 6	3GBP353810-•DG	991	95,8	95,8	95,2	0,83	676	7,0	3420	2,4	2,6	15,5	2500	75
400	M3BP 355LKB 6	3GBP353820-•DG	991	95,9	96,1	95,7	0,84	754	6,5	3854	2,3	2,3	18,5	2600	75
400	M3BP 400LA 6	3GBP403510-•DG	992	96,1	96,3	95,9	0,84	753	6,6	3849	2,0	2,4	17	2900	76
450	M3BP 400LB 6	3GBP403520-•DG	993	96,0	96,1	95,7	0,85	842	6,4	4326	2,1	2,5	20,5	3150	76
500	M3BP 400LC 6	3GBP403530-•DG	992	96,1	96,3	96,0	0,86	925	6,5	4813	2,2	2,4	22	3300	76
560	M3BP 400LD 6	3GBP403540-•DG	993	96,4	96,5	96,2	0,87	1015	6,2	5390	2,0	2,6	24	3400	77
630	M3BP 450LA 6	3GBP453510-•DG	993	96,3	96,5	96,2	0,85	1170	5,5	6057	0,9	2,3	31	4150	81
710	M3BP 450LB 6	3GBP453520-•DG	994	96,8	97,0	96,7	0,86	1297	6,6	6819	1,2	2,4	37	4500	81
800	M3BP 450LC 6	3GBP453530-•DG	994	96,9	97,0	96,6	0,85	1469	6,8	7682	1,1	2,5	41	4800	81

Data sheet ACS 1000, ACS 1000i

Inverter type
Three-level Voltage Source Inverter (VSI) with fast-switching power semiconductors – Integrated Gate Commutated Thyristors (IGCTs), without parallel or series connected devices

Motors
Induction motors:
ACS 1000: 315 – 2000 kW air cooled
1800 – 5000 kW water cooled
ACS 1000i: 315 – 2000 kW air cooled

Standards
All common standards including EN (IEC), CE, UL, cUL, GOST

Input
ACS 1000:
Any medium voltage level, 50 Hz or 60 Hz, can be applied to the appropriate primary side of the converter input transformer.

ACS 1000i:
Voltage range: 4.16 – 7.2 kV, 60 Hz/6.0 – 6.6 kV, 50 Hz, on request up to 11 kV

Variation (ACS 1000, ACS 1000i):
-5% / +10% of nominal voltage, down to -25% safe operation with derated output.
Higher variation on request.

Auxiliary voltage
400 VAC ±10%, 50/60 Hz
480 VAC ±10%, 60 Hz
575 VAC ±10%, 60 Hz, 3 phase

Efficiency of converter
ACS 1000 typically > 98%
ACS 1000i typically > 96% (incl. integrated transformer)

Input power factor
Fundamental: > 0.97
Total: > 0.96

Overload capacity
Standard: Normal use, 10% short term overload capacity allowed for one minute every 10 minutes
Optional: For higher overload capacity contact ABB

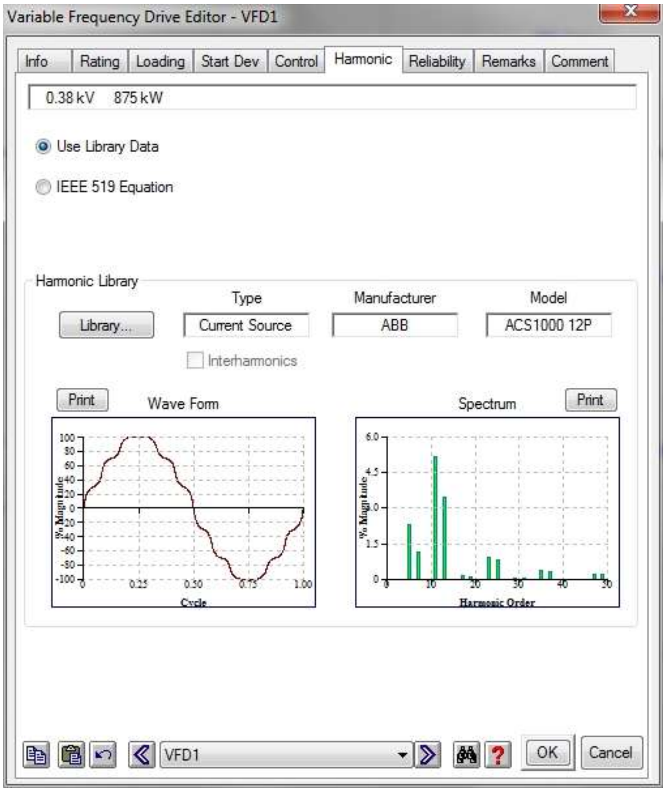
Ambient temperature
+1° C to 40° C (higher with derating)
34° F to 104° F (higher with derating)

Enclosure classes
ACS 1000
Air cooled: IP21, IP22, IP31, IP32, IP42
Water cooled: IP31, IP54
ACS 1000i IP21, IP42

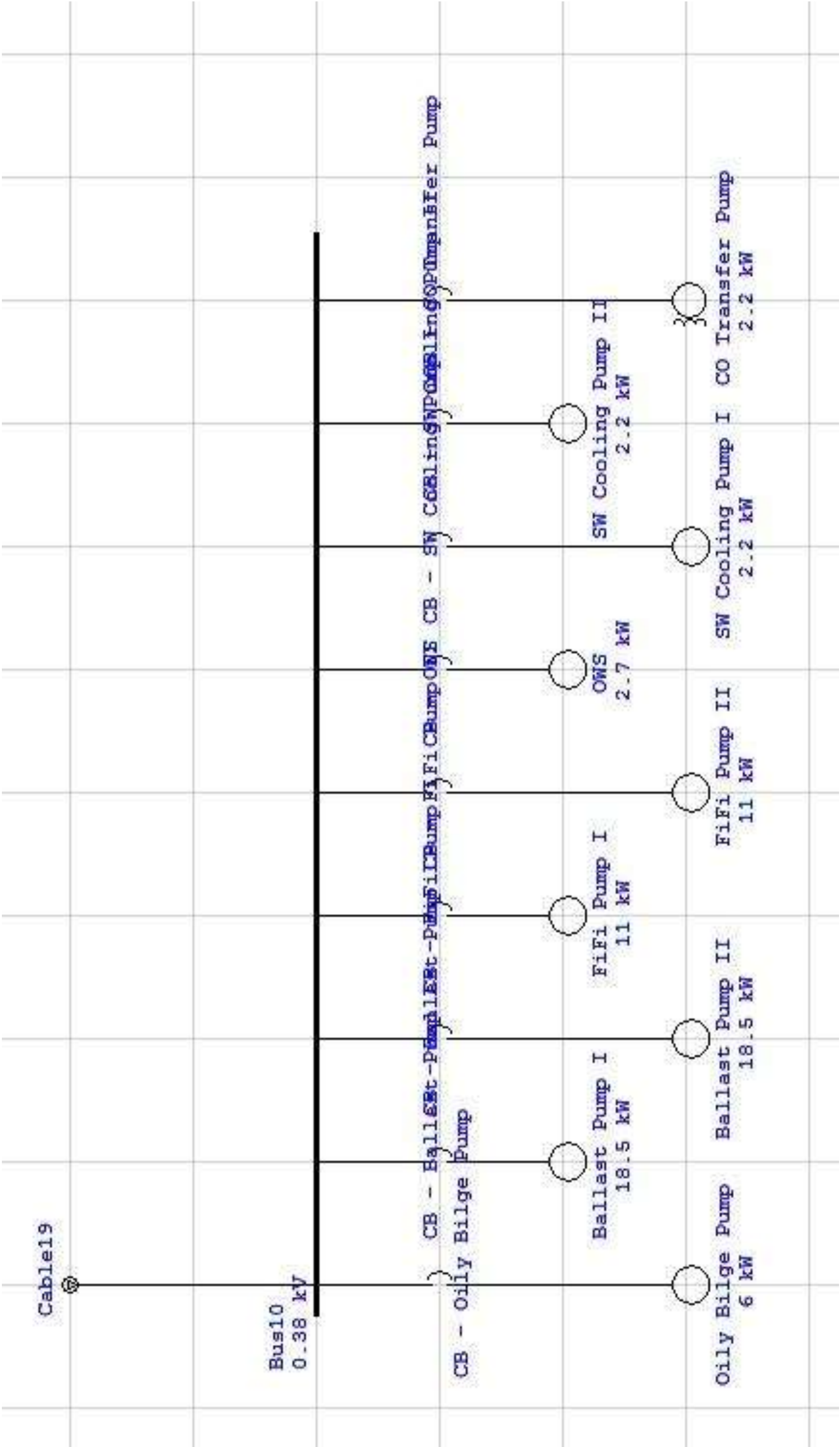
Control interface (optional)
- All common fieldbuses including Profibus, Modbus, Allen-Bradley DeviceNet, Ethernet, ABB Advant Fieldbus AF100 (others on request)
- Extensive range of additional I/O features available

Standard protection functions
Auxiliary voltage fault, cabinet temperature supervision, overcurrent, short circuit detection, earth fault, input phase loss, output phase loss, overvoltage, motor overload, motor underload, motor stall and overspeed protection, communication fault, main circuit breaker supervision and many others

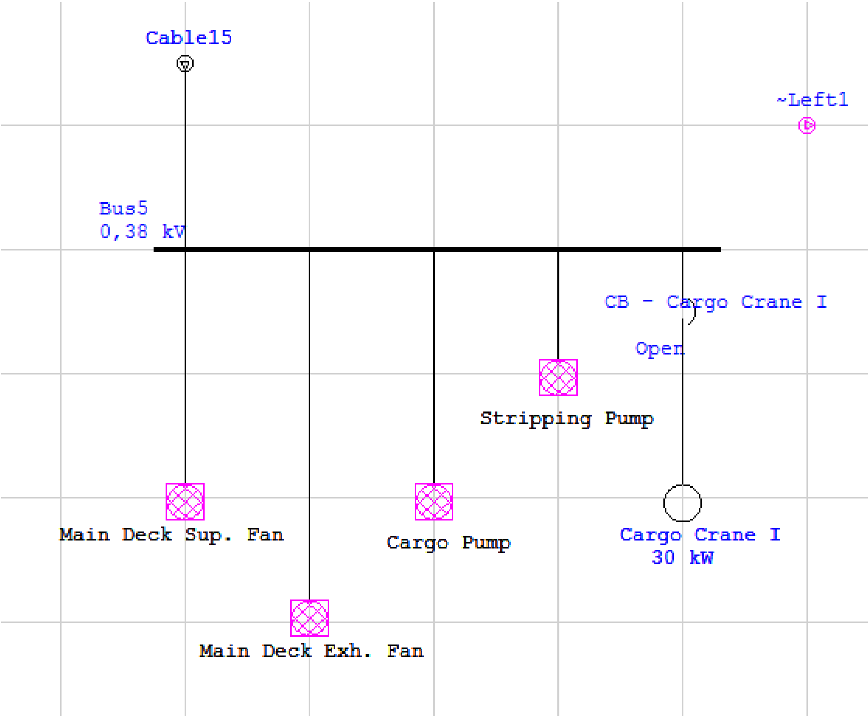
- **3-Phase Induction Motor and VFD Specification on ETAP**



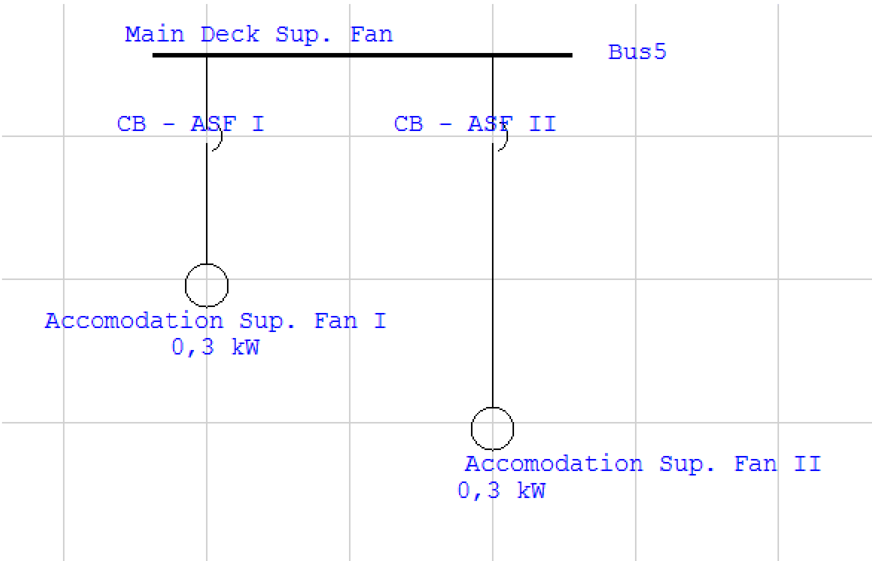
- **Junction Power Engine Room (inside Composite Network)**



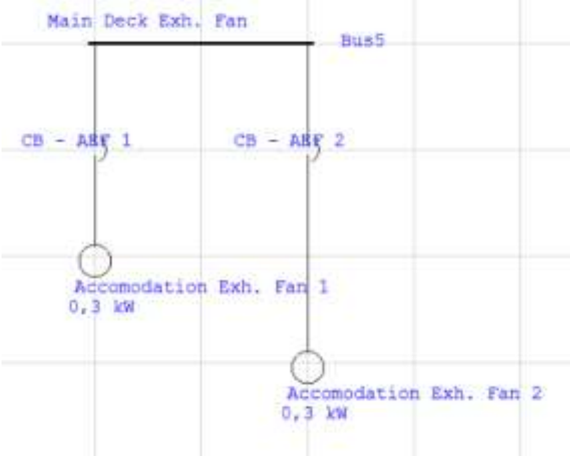
- **Junction Power Main Deck (inside Composite Network)**



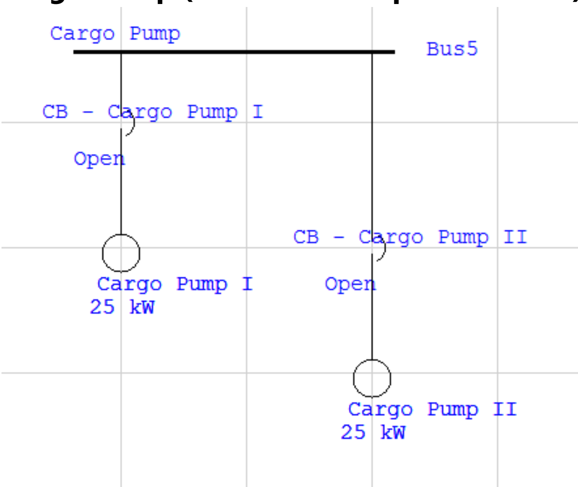
- **Main Deck Supply Fan (inside AC Composite Motor)**



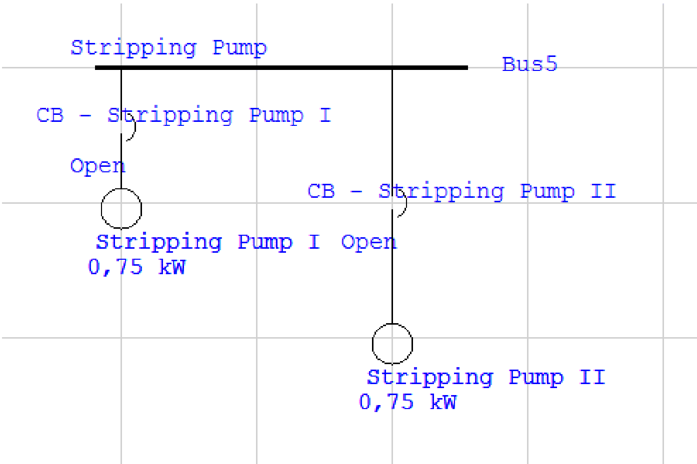
- **Main Deck Exhaust Fan (inside AC Composite Motor)**



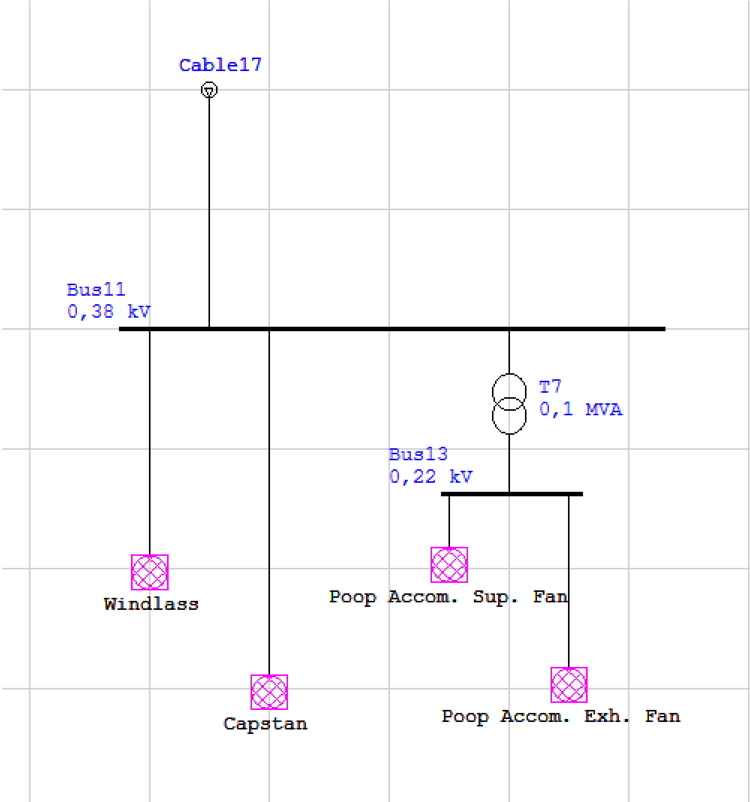
- **Cargo Pump (inside AC Composite Motor)**



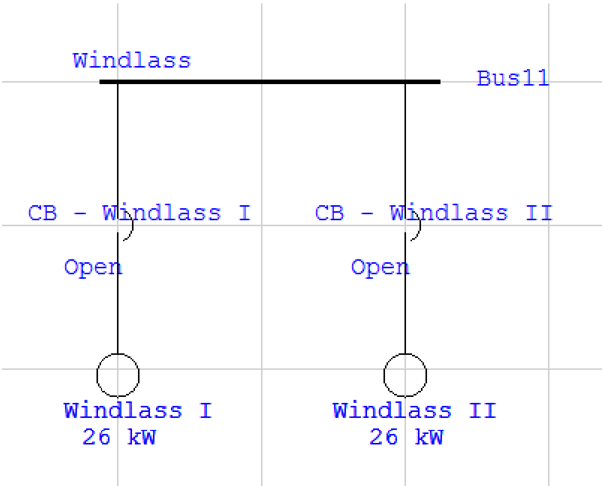
- **Stripping Pump (inside AC Composite Motor)**



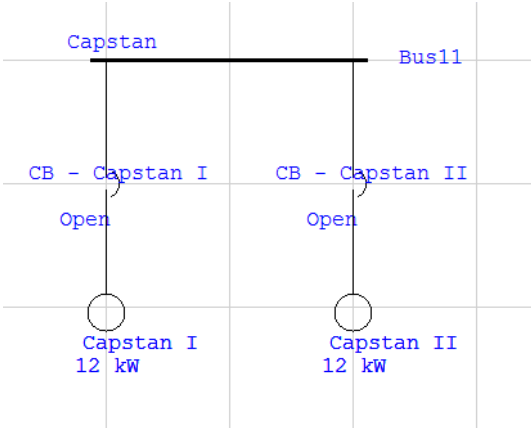
- **Junction Power Poop Deck & Boat Deck (inside Composite Network)**



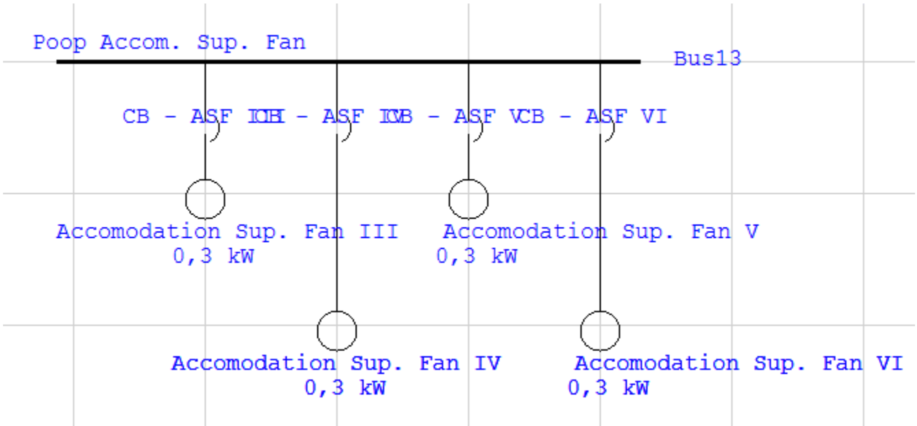
- **Windlass (inside AC Composite Motor)**



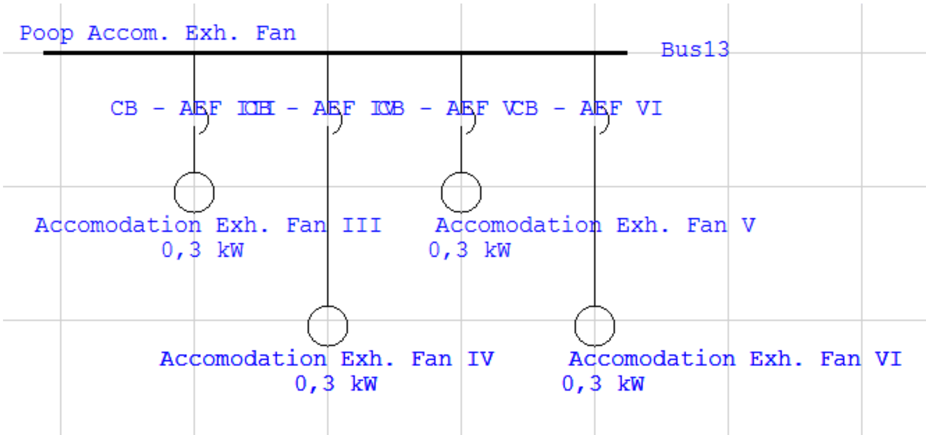
- **Capstan (inside AC Composite Motor)**



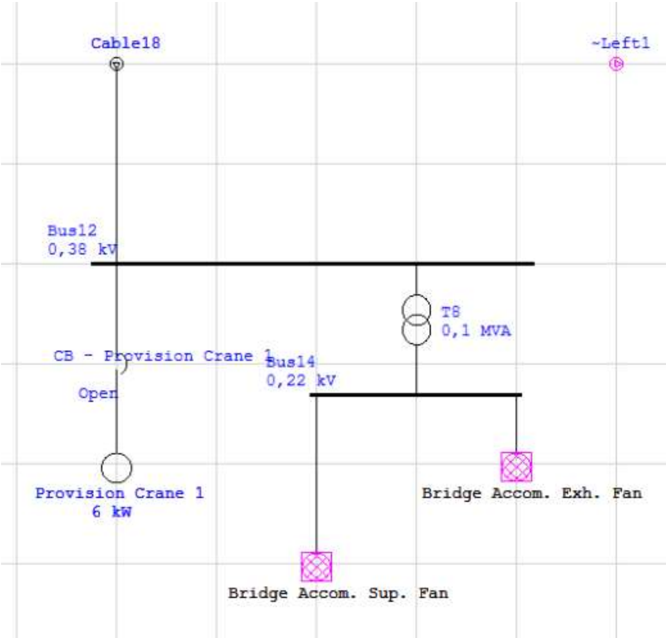
- **Poop Deck Accomodation Supply Fan (inside AC Composite Motor)**



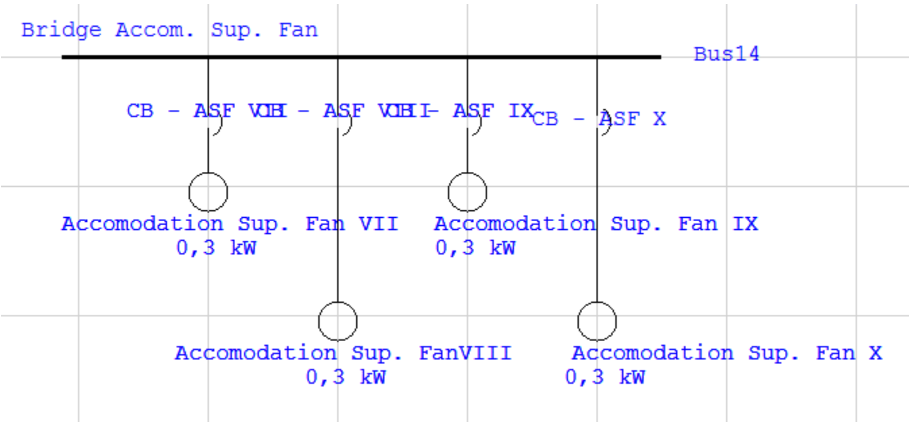
- **Poop Deck Accomodation Exhaust Fan (inside AC Composite Motor)**



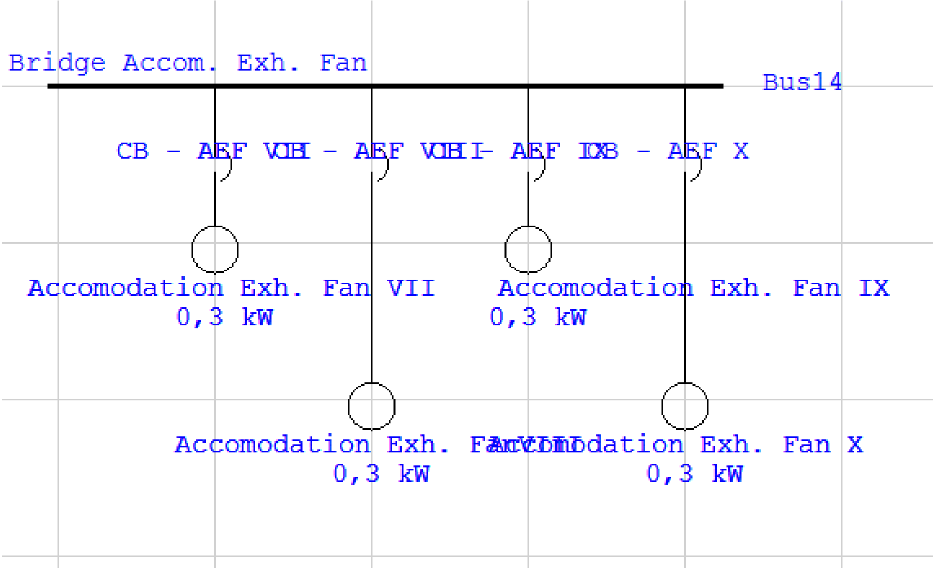
- **Junction Power Bridge Deck & Navigation Deck (inside Composite Network)**



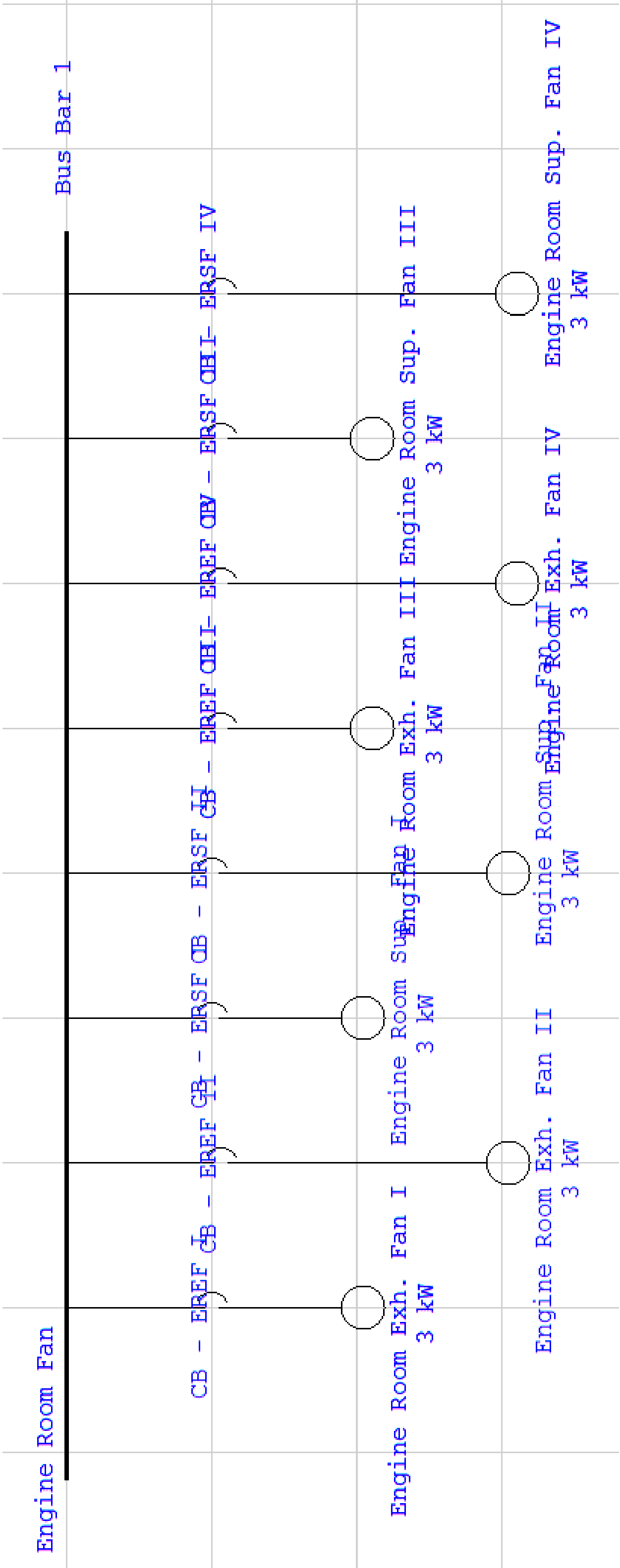
- **Bridge Deck Accomodation Supply Fan (inside AC Composite Motor)**



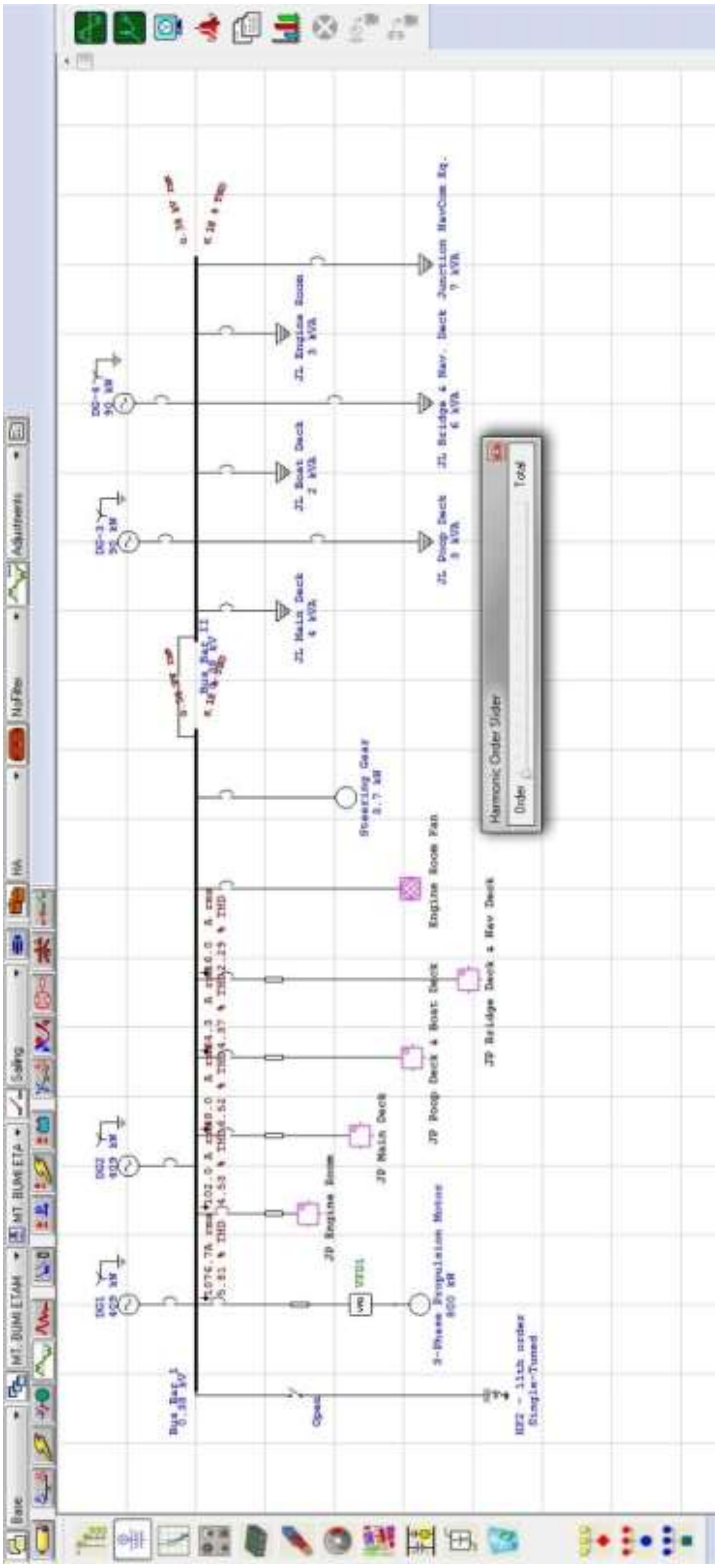
- **Bridge Deck Accomodation Exhaust Fan (inside AC Composite Motor)**



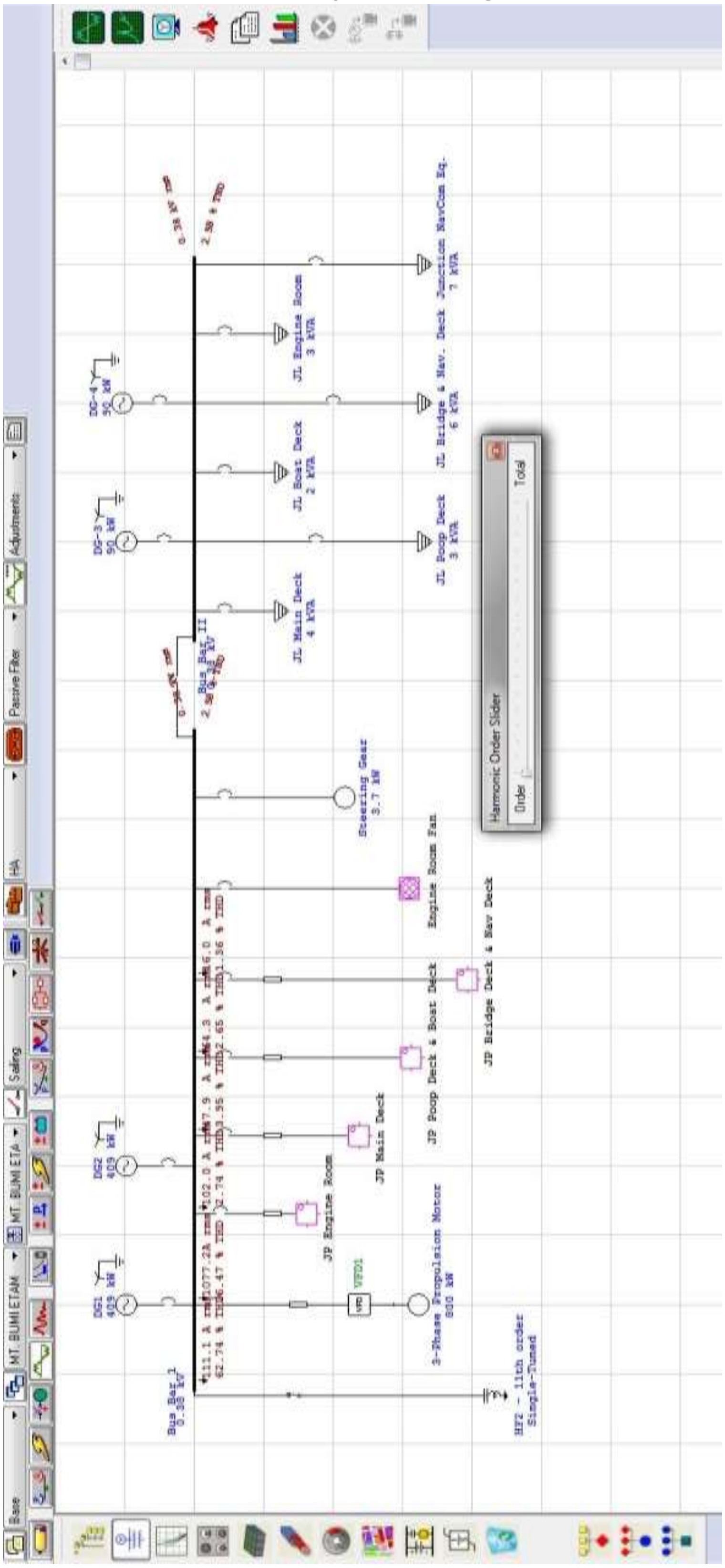
- **Engine Room Fan (inside AC Composite Network)**



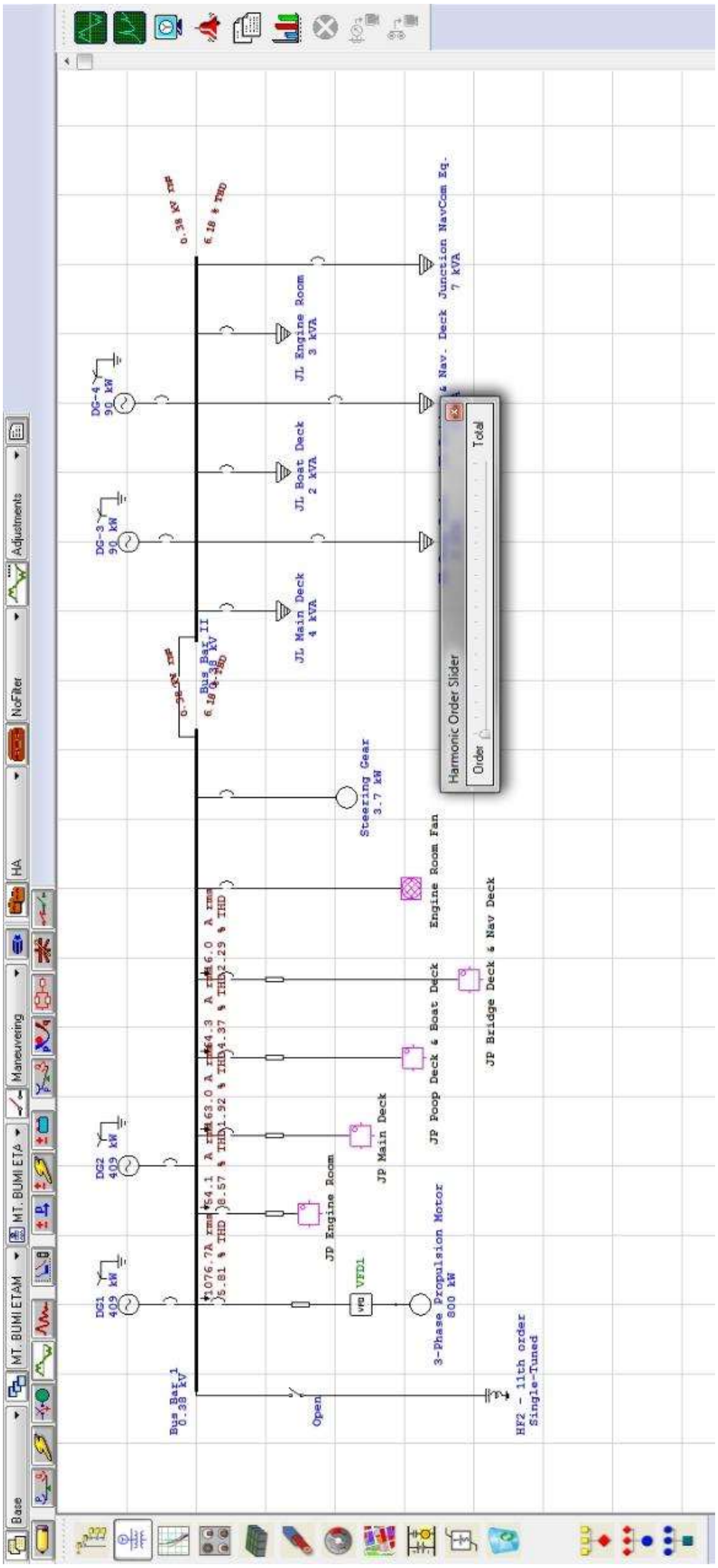
- **Harmonic Load Flow Analysis – Sailing, No Filter**



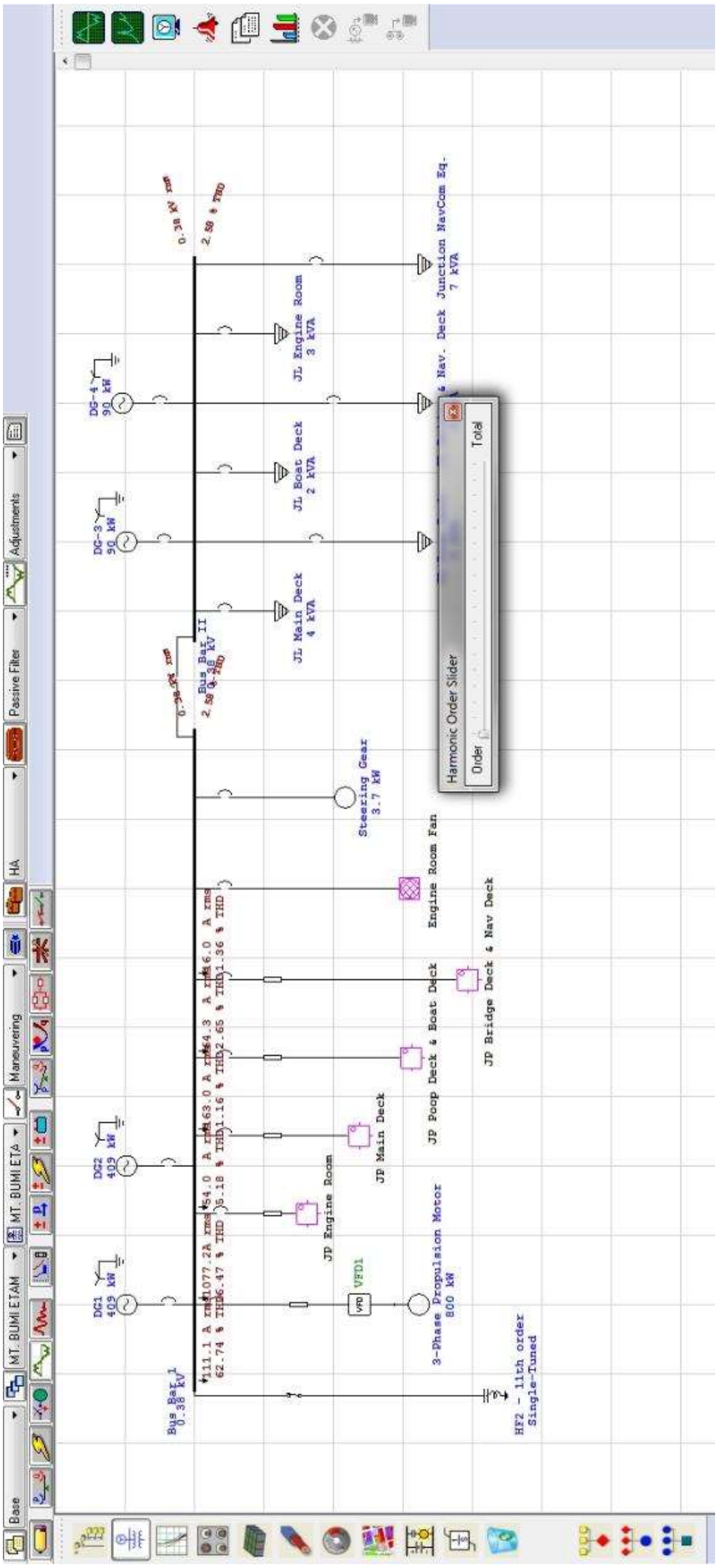
- **Harmonic Load Flow Analysis – Sailing, With Passive Filter**



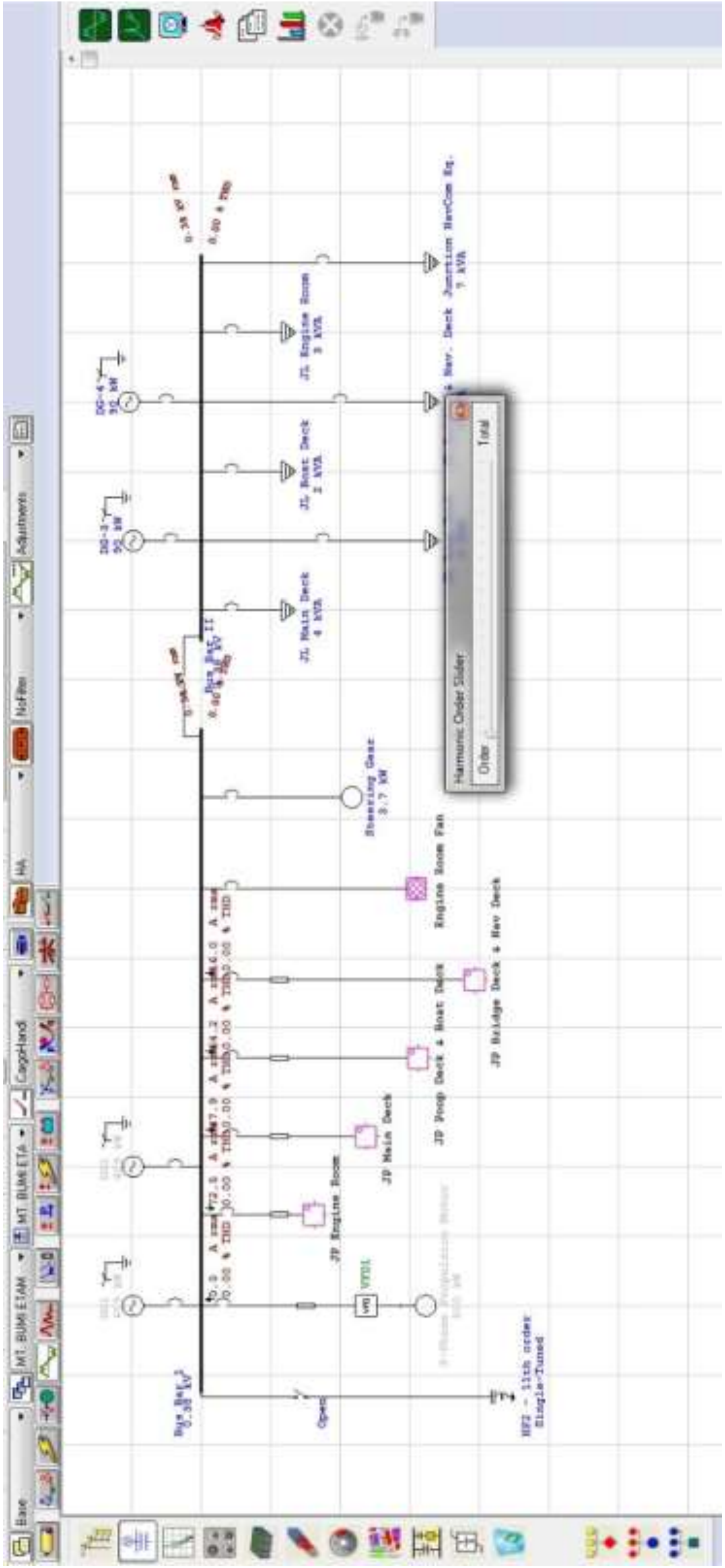
- **Harmonic Load Flow Analysis – Maneuvering, No Filter**



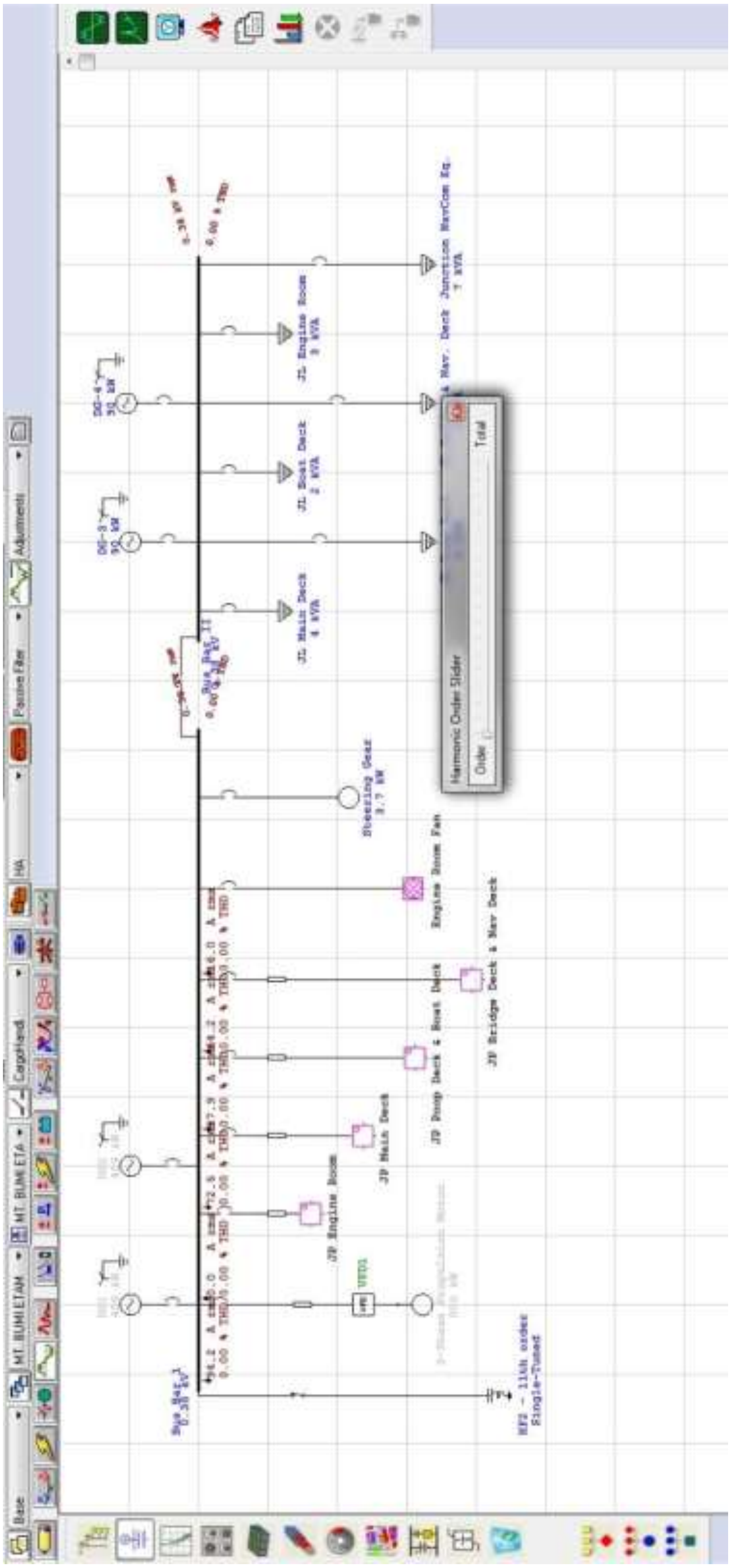
- **Harmonic Load Flow Analysis – Maneuvering, With Passive Filter**



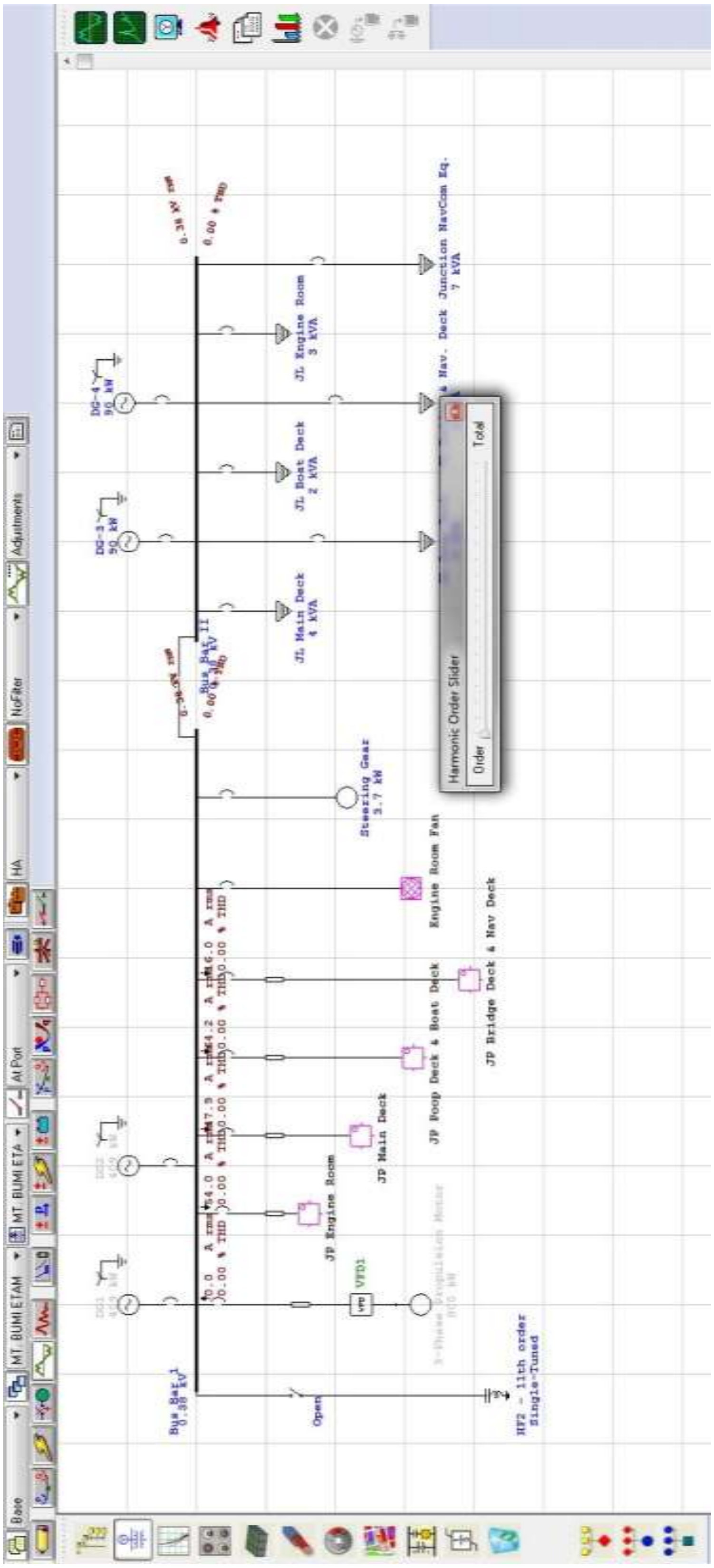
- **Harmonic Load Flow Analysis – Cargo Handling, No Filter**



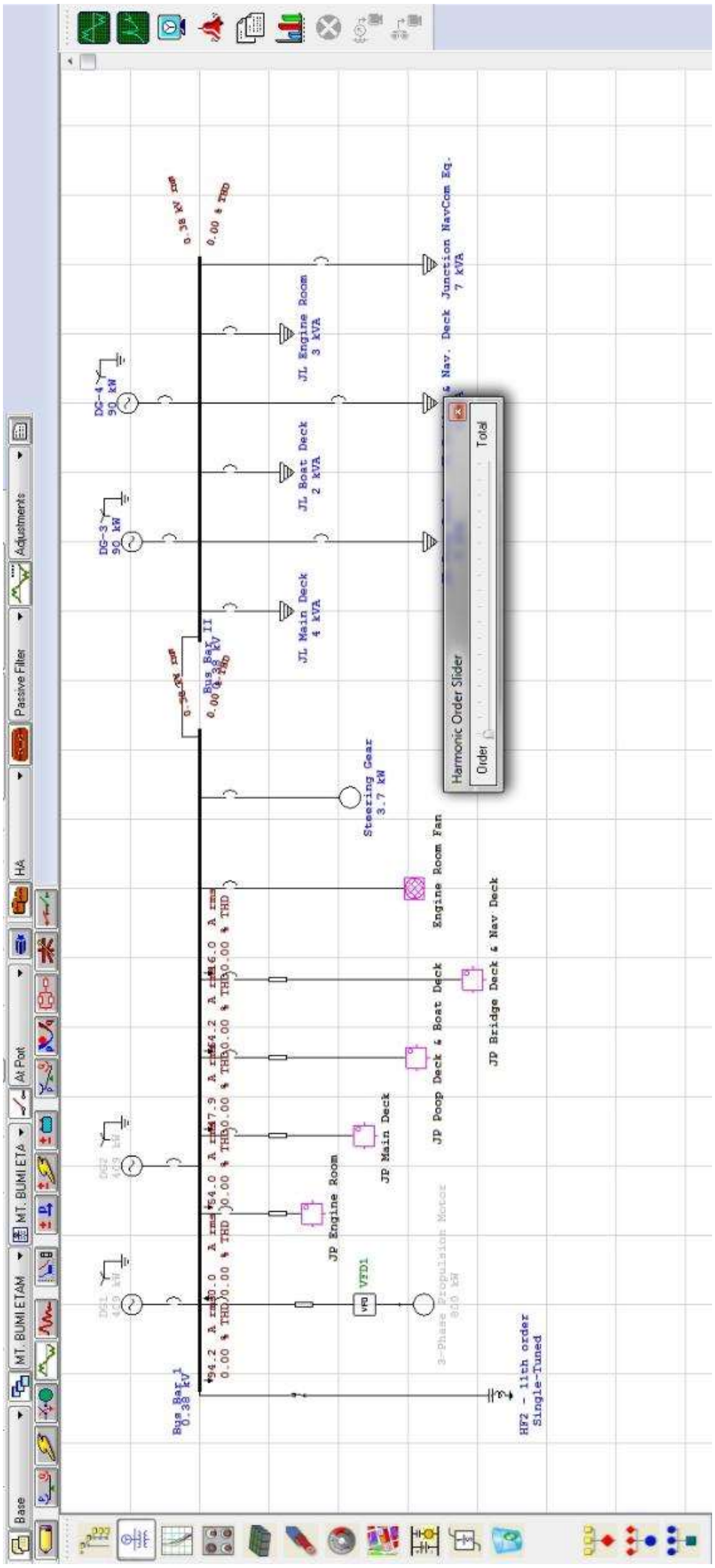
- **Harmonic Load Flow Analysis – Cargo Handling, With Passive Filter**



- **Harmonic Load Flow Analysis – At Port, No Filter**



- **Harmonic Load Flow Analysis – At Port, With Passive Filter**



- **Harmonic Load Flow Analysis Report**

  This report can be found on the CD of this thesis, the Harmonic Load Flow Analysis Report are including on condition;

  - Sailing, No Filter
  - Sailing, With Passive Filter
  - Maneuvering, No Filter
  - Maneuvering, With Passive Filter

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AUTHOR BIOGRAPHY

Faisal Muhammad Satrio was born in Surabaya on 25 June 1995. The author grew up in Bekasi with his parents. His father was a former sailor, a former chief engineer. Since childhood, the author already has a tendency to like things related to machines and electronics. He was educated and graduated from elementary school in SDIT Al-Husna TWA Bekasi, junior high school in SMP Mutiara 17 Agustus 1 Bekasi, and senior high school SMAN 8 Bekasi. He was beginning his study in Institut Teknologi Sepuluh Nopember on year 2013 through a Program Kemitraan dan Mandiri (PKM) then accepted as a student in double degree program, department of marine engineering, faculty of marine technology.

During his college life in ITS, he was active in some organization, he became an internal affair staff in his second year and became head of organization constitution in internal affair in the third year of college life on BEM-FTK ITS. On fourth year, he was registered as a member in Marine Electrical and Automation System (MEAS) laboratory.

Besides that, the author activity outside the collage was doing a small business. From selling goods, foods, phone and computer services, set up a clothing store, until became a distributor and marketing a local product.

There are some inspirational quotes from great people that the author was inspired by, there are;

"Speak a good word, or remain silent."
Prophet Muhammad SAW (Peace be upon Him)

"Remember, your mind is your greatest asset, so be careful what you put into it."
Robert T. Kiyosaki